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A SPECTROSCOPIC INVESTIGATION OF DR. G. URBAIN'S PREPARATIONS OF TERBIUM[1]

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Although terbium was discovered as early as 1843, no one of the many chemists who have occupied themselves with its production have succeeded until recent years in obtaining a preparation that is even tolerably pure, from which the chemical properties and the spectrum of terbium could be studied. As we know today, Mosander, the discoverer of this element, had at most only from 1 to 2 per cent. of terbium in the substance which led him to the discovery; and the only thing that he could establish was that terbium formed a dark "superoxide" which strongly colored the other earths, which could be reduced on heating in a current of hydrogen.

The reasons for the failure of these attempts at isolation lie in the fact that terbium belongs to those rare elements which never occur except in excessively small quantities, and that its separation is even today one of the most difficult problems in the chemistry of the rare earths.

Under these circumstances it is not surprising that many chemists, and among them Bunsen, doubted the existence of terbium, and the contention lasted for many years, until finally its existence was conclusively demonstrated.

[1] Translated from advance proofs of a paper appearing in the *Sitzungzberichte der Kgl. Akad. der Wiss.*, Berlin, 1906, p. 384.

Undoubtedly the greatest advance was made by Lecoq de Boisbaudran and Demarcay. Lecoq had a few centigrams of the preparation, at least fairly rich in terbium, since he succeeded in finding the faint absorption band at λ 488 $\mu\mu$, but he was not in a position to adequately separate his preparation from the related earths. He further did not recognize that he was dealing with terbium, but thought he had found a new element (Zδ). Later Demarçay[1] had a terbium of similar properties in which, independently of Lecoq, he found the band at λ 488, and was even able to give several lines of the spark spectrum. He also believed that he had found a new element (Γ). These two chemists are indeed the only ones who attained a fairly strong concentration of terbium in their preparations.

The Parisian chemist, Dr. G. Urbain,[2] was the first to succeed in actually isolating this interesting substance, after he had carried on for several years continuous fractionations by new methods which he invented, and obtained 7 grams of the costly substance in very great purity. He was able at the same time to furnish the chemical proof that his preparation represented a single element, that this was identical with Mosander's terbium and had an atomic weight of 159.2. The only thing lacking for a complete description of this element was the accurate investigation of its spectrum, by which alone an element is characterized in a wholly unambiguous way, along with its chemical properties. The investigation of the spectrum is of the highest importance, particularly in the case of the rare earths which possess such an uncommon similarity in their chemical characteristics. Frequently observers have thought they had found new elements when they were actually dealing only with mixtures of several of these so closely related substances. Furthermore, the spectroscopic investigation alone can settle what related elements of this group are contributing impurities, and whether the amount of the impurity is so low that the preparation can be regarded as chemically pure. For this reason spectrum analysis has since its foundation stood in the closest relation to the chemistry of the rare earths, and exact results have been obtained only by the co-operation of the chemist and the spectro-

[1] *Comptes Rendus*, 131, 387, 1900.

[2] *Ibid.*, 139, 736, 1904; 141, 521, 1905.

scopist, as Kayser[1] has so aptly shown in the introduction to his paper on the spectrum of yttrium.

Dr. Urbain then requested me to complete the researches in this direction, and, thanks to the numerous and exceedingly valuable preparations which he put at my disposal, the present research could be carried out and the proof furnished, with all the precision desired, that we were concerned with an actual element. In spite of the very great purity of Urbain's preparations, the work could be executed with the prospect of success only by the spectroscopic investigation of a large number of its fractionations, in addition to terbium itself, as well as of its related elements, inasmuch as no previous spectroscopic investigations were available (with exception of the eight spark lines given by Demarçay), and indeed under the circumstances such investigations could not exist. As a matter of fact, Messrs. Exner and Haschek, after the investigation of a whole series of fractionations of the yttrium earths, expressed the opinion that terbium does not exist.[2] This investigation was greatly simplified by the fact that Urbain succeeded in producing, in an adequate degree of purity, dysprosium, which follows terbium and which hitherto had never been produced, and was only known by a few absorption lines. Thus, it has now been possible to follow the behavior of the terbium lines from their appearance (in gadolinium) to their disappearance (in dysprosium).[3]

For photographing the spectra I employed a concave grating spectrograph[4] of the Astrophysical Observatory at Potsdam, which made it possible to obtain with a single exposure on a film (mounted on a stiff celluloid foundation) the second order spectrum from λ 2200 to

[1] "Die Bogenspektren von Yttrium und Ytterbium," *Anhang zu den Abhandlungen d. K. Preuss. Akad. d. Wiss.*, 1903.

[2] *Bogenspektren der Elemente*, I. p. 19. No criticism should be made of these gentlemen on that account, for they had at their service inadequately differentiated fractionations, and too impure preparations. For instance, their "holmium" consisted of gadolinium, terbium, dysprosium, neoholmium, yttrium, and erbium.

[3] Before this investigation was concluded, Dr. Urbain sent me a series of the purest preparations of dysprosium, designated as *Dy* 31, 35, 38, 41, of which *Dy* 41, which I have already partially investigated, contains very faintly only a few of the very strongest terbium lines.

[4] A description of this apparatus may be found in the *Zeitschrift für Instrumentenkunde*, **25**, 371, 1905.

λ 4700. On account of the excessive cost of the preparation, only very small quantities were available, for which reason it would be undesirable to make several exposures for the different regions of the spectrum. The substances in the form of oxides were vaporized on carbon rods which had previously been thoroughly heated, with a current-strength of about 15 amperes at 120 volts. Iron served as comparison spectrum, but in order to eliminate any changes in the apparatus between the two exposures, a very small quantity of the substance under investigation was vaporized on the carbon crater simultaneously with the iron. Then, if there were any small displacements of the spectrum with reference to the comparison spectrum, such as might be due to slight changes of temperature, this could be determined by the measurement of the lines common in the two strips of spectrum, and hence they could be made harmless. The films were laid between sheets of optically plane glass, and measured on machine No. 4 of this Observatory, the screw of which has no periodic errors, as has been shown by an investigation by myself and Dr. Münch. The progressive errors, which were also determined, run very smoothly and are small.

I have employed the values given by Exner and Haschek for the wave-lengths of the iron lines, for the following two reasons. Too small a number of the decidedly more accurate wave-lengths of the iron lines by Kayser are available for an investigation in which the lines are needed at small intervals, so that, unfortunately, I could not employ them. Furthermore, the wave-lengths of the terbium lines ought to be referred as closely as possible to the system of Exner and Haschek, since the tables of wave-lengths by these gentlemen are at present the only complete ones, and they deservedly have found a very wide circulation. It is true that the accidental errors in the values of Exner and Haschek often reach several hundredths of an Ångström unit, but I hope that I have made myself somewhat independent of these by the use of a great number of lines, and by a graphical correction of their wave-lengths. The precision of the wave-lengths of the terbium lines as given below is the same as that of the measurements of Exner and Haschek.

Dr. Urbain placed at my disposal the following preparations:

A. *Gadolinium.*—(1) Entirely pure gadolinium from the minerals monazit and xenotin.

(2) A number of gadolinium fractionations from europium to terbium. The oxide of the last of these (*Gd* 37) is of faint yellow color and gives the strongest terbium lines quite conspicuously.

B. *Terbium.*—(1) "Nitrates doubles de *Ni. Gd-Tb* (14)." The oxide which was strongly yellow already shows all of the strong terbium lines and those of medium strength.

(2) "$Z\delta_7$." The dirty dark yellow oxide already gives all the terbium lines along with those of gadolinium.

(3) "$Z\delta_5$." The oxide is almost black with a touch of reddish-brown. It is an almost pure terbium, but it still yields the strong lines of gadolinium in the arc.

(4) "$Z\delta_3$" and (5) "$Z\delta_1$." The oxides are almost black with a faint touch of the reddish-brown. The spectrum is essentially that of terbium.

(6) "*Tb-Dy* 7, 8, 9." The oxides are of the dirty dark yellow. All the lines of terbium and almost all those of dysprosium are present. The three fractionations show only very small differences.

C. *Dysprosium and neoholmium.*—(1) "Queues du fractionnement des ethylsulfates de *Tb*; traces *Ho*, tres-riches *Dy*" (Q). The oxide is of a dirty bright yellow color. The lines of dysprosium here appear in full number, and faintly those of terbium.

(2) "Terres riches en *Ho*, pauvres en *Dy*, riches en Y. Fraction (4–5)" (*Ho*). The oxide is white with a faint touch of yellowish. The spectrum contains essential lines of yttrium, the strong lines of neoholmium and the stronger lines of dysprosium.

(3) "*Dy* 31, 35, 38, 41." The oxide is of a faint dirty yellow. *Dy* 41 is a pure dysprosium.

Complete measurements vere made of the following photographs of these preparations: $Z\delta_7$, $Z\delta_5$, $Z\delta_1$, *Tb-Dy* 8, Q, with a total of 10,300 lines beside 2000 iron lines. Subsequently I also worked upon the greater part of *Dy* 41 . Some single lines were measured in all fractionations. All of the plates, measurements and reductions were made exclusively by myself.

The material yielded by these measures I have critically discussed

in order to obtain certainty as to the impurities. First, with the aid of the tables of Exner and Haschek, those lines were eliminated which were due to elements not belonging to the group of rare earths. This included the lines coming from the carbon rods, particularly *Ba*, *Ca*, *Al*, and *Si*. It is probable that the lines of the different band spectra of carbon were not fully eliminated, but I believe that only the fainter ones are left in the tables, since during the measurement all the stronger ones could be recognized by comparison with the control spectrum in which they also occurred, and they could be left out. The ultra-violet cyanogen bands confused the image of the spectrum considerably, and they certainly suppressed or concealed some of the fainter lines of terbium in these regions. Of the other elements we should particularly have expected *Pt*, *Ni*, *Bi*, and *Mg*, which might have crept in during the fractionation; but the preparations proved to be entirely free from these elements. The same was true of the rare earths *Ce*, *La*, *Pr*, *Nd*, *Sa*, *Eu*. Gadolinium was the first element whose lines appeared. Since Messrs. Exner and Haschek dealt in their investigations with gadolinium from Demarçay, I sought out the impurities on the basis of those tables, and employed my own photographs of Urbain's preparations only in isolated cases.[1] I have collected in Table I all the stronger lines of gadolinium which did not coincide with terbium lines, and I give the intensities (I) which they had on the spectra I measured.

It appears from this table that Q is wholly free from gadolinium, and *Tb-Dy* 8 practically so, while $Z\delta_1$ only contained very slight traces.

For eliminating the lines of yttrium I have employed the tables of Kayser and those of Exner and Haschek, and give the results in Table II. I would particularly point out that, according to this, yttrium is certainly lacking in $Z\delta_7$, $Z\delta_5$, and $Z\delta_1$. All the yttrium lines are also absent from *Dy* 41.

For hunting down the lines of the other yttrium earths I have been completely dependent on my own researches, since all the preparations used by Exner and Haschek were very complicated mixtures; indeed,

[1] I have not been able to find the strong gadolinium line λ 4063.62 (20) of Exner and Haschek's tables. On my plates there are at this point the two lines λ 4063.54 (4) and λ 4063.76 (2).

in the case of some of them (erbium, thulium, and ytterbium) the question of their elementary character is still doubtful. Fortunately Urbain had succeeded in isolating dysprosium, so that by the measurement and provisional tabulation of the dysprosium spectrum I was able to select at least those lines which most particularly come into consideration as impurities. Provisional values of the wave-lengths and intensities of the stronger dysprosium lines are contained in Table III, in so far as they did not coincide with terbium lines, and the intensities of these lines in the terbium preparations are again given with them.[1]

TABLE I

Exner and Haschek		I (Eberhard)				Exner and Haschek		I (Eberhard)			
λ	I	$Z\delta_2$	$Z\delta_1$	*Tb-Dy*8	Q	λ	I	$Z\delta_2$	$Z\delta_1$	*Tb-Dy*8	Q
3027.74	8	6				3814.18	10	3			
3100.66	10	6	0	0		50.85	8	1			
3350.63	8	6	2	0		51.15	8	1			
3418.87	8	3				52.65	10	6			
22.62	10	6	2			94.88	8	3			
39.37	8	3				3916.70	10	5	1		
40.13	8	5				4037.49	10	3			
81.49	8	4				38.03	8	3			
3545.94	10	3	0			49.59	8	4			
85.12	10	3				50.05	10	5			
3646.36	15	4				63.62	20				
54.78	8	2				70.51	10				
56.31	8	3	0			85.73	10	4			
64.78	8	5	0			98.80	10	3	1	0	
71.39	10	3				4212.16	8	4			
3712.88	8	5				26.02	8	4			
43.68	10	3				62.24	10	7	0		
68.60	20	7				4327.29	10	6			
96.62	10	2				42.35	10	3			

TABLE II

Exner and Haschek		I (Eberhard)			Exner and Haschek		I (Eberhard)		
λ	I	$Z\delta_2$	$Z\delta_1$	*Db-Dy*8	λ	I	$Z\delta_2$	$Z\delta_1$	*Db-Dy*8
3600.91	10			0?	4177.74	30			
3710.48	20			1	4309.81	20			
3774.52	20				4375.12	50			
3788.88	30			2	4398.25	20			
4077.54	20				4422.81	10			
4102.57	20								

[1] For the purpose of comparison I have added Exner and Haschek's wave-lengths and intensities in the spectrum of "holmium," which appear to belong to dysprosium.

TABLE III

Eberhard						Exner and Haschek		Eberhard						Exner and Haschek	
λ	Q	*Tb-Dy8*	Zb_1	Zb_5	Zb_7	λ	I	λ	Q	*Tb-Dy8*	Zb_1	Zb_5	Zb_7	λ	I
2906.53	6	4				.53	2	3266.32	5	2				.33	2
14.09	6	0	0			.08	3	69.24	6	3				.22	2
34.62	6	5				.60	3	72.88	6	3				.85	1
44.70	5	2				.67	3	80.25	5	4	1			.22	3
53.88	5	1				.82	2	88.06	5	2				.05	2
77.57	6	3	0			.53	1	3308.97	9	6	2			.99	10
86.06	7	2				.04	dp. 2,2	16.42	7	4	2			.42	4
91.73	5					.73	2	17.22	6	3	1			.23	2
3002.51	5	2				.51	2	20.02	7	6	3			.02	5
03.89	6	2				.86	2	41.12	6	4	1			.12	4
15.22	6	2				.16	2	42.00	5	3	2			.00	2
15.82	6	4				.77	2	58.38	7	2				.39	2
17.10	6	2				.09	dp. 1, 2	68.24	6	5	1			.21	5
25.73	6	2				.71	2	84.23	8	1				.21	2
26.30	6	5	0			.26	3	85.15	9	7	4	0		.19	10
29.95	5	2				.91	2	88.83	6	0					
36.83	5	2				.80	2	96.31	7	6	0			.31	6
47.68	7	4				.66	3	3407.94	8	5	3			.94	6
51.60	5	3				.57	2	14.95	6	4				.95	3
52.44	5	2				.45	2	19.73	8	4	2	1		.72	4
60.17	5	2				.14	2	29.15	6	2				.23	1
62.76	5	4	0			.72	3	29.57	7	4	2	0		.56	2
72.03	6	5	0			.03	3	45.73	8	6	3			.72	8
73.68	6	4				.66	3	50.05	5	3				.02	2
3102.04	7	3				.02	3	54.49	6	3	2			.50	dp. 4, 2
03.36	5	2				.36	3	63.51	6	2	0			.46	1
03.97	5	3				.94	3	71.27	6	3				.27	2
05.12	5	0				.10	2	71.73	7	3				.72	3
20.28	5	3				.30	2	77.23	6	4	3			.21	4
28.51	7	4	0			.54	3	97.97	5	2				.93	2
40.74	6	4	2	0		.75	4	3501.59	5	2				.56	2
41.25	6	4	0			.23	4	04.68	7	3				.64	3
43.92	5	2				.93	2	17.41	6	3	1			.38	3
46.25	6	3				.24	2	24.15	8	5	3			.19	10
52.00	5	3	1			.00	2	31.89	10	10	3	2		.90	20
87.80	6	3	0			.80	2	35.12	5	4	3	0		.12	8
93.41	6	3				.42	3	36.18	6	4	3	0		.15	8
3205.61	6					.57	1	38.67	7	5	3			.65	8
08.96	6	3	2	0		.94	2	42.48	6	4	1			.50	6
12.20	5	0				.16	1	45.13	5	3	1	0		.12	2
15.31	6	3	0			.30	3	50.39	7	6	3			.37	5
16.75	8	7	3			.77	6	51.77	5	3	2			.79	4
23.39	6	3				.41	3	63.31	5	3	2			.30	4
25.23	6	2				.23	2	73.99	5	4				.99	3
36.77	7	3				.75	2	74.30	5	3	1	0		.31	4
48.47	5	3				.45	2	76.42	5	3	2			.40	5
56.38	5	3	0			.40	2	77.05	5	4	2			.01	5
60.82	5	3	2	1		.84	2	96.21	5	2				.18	2
66.12	5	3	2			.12	1	3602.97	5	1				.96	2

TABLE III—*Continued*

Eberhard						Exner and Haschek		Eberhard						Exner and Haschek	
λ	Q	*Tb-Dy8*	Zb_1	Zb_5	Zb_7	λ	I	λ	Q	*Tb-Dy8*	Zb_1	Zb_5	Zb_7	λ	I
3614.24	4	2				.21	2	3983.78	7	6				.82	10
24.43	5	3				.40	2	84.40	6	4				.38	4
35.41	6	3				.39	3	96.84	6	6				.90	10
36.38	5	2						4000.59	10	9	4	1		.67	20
37.45	7	3				.40	3	11.44	5	5	0			.42	3
44.05	6	2				.04	3	24.57	6	4	0	0		.56	3
45.54	10	7	4	2		.52	10	27.94	6	4	0			.91	1
46.01	5	4	3			.96	3	42.12	6	4				.11	3
72.45	6	4	3			.43	4	46.13	10	10	4	2		.11	20
74.20	6	5	4			.21	4	48.51	5	3				.46	2
85.96	7	4				.92	3	50.73	7	7	3			.72	10
94.98	7	6	1	0		.98	8	73.31	8	6	4	2		.30	10
97.65	6	3				.65	3	78.10	10	9	4	0		.11	15
98.34	6	4	1			.32	4	4111.50	7	5	3			.51	10
3701.79	6	3				.76	3	19.45	6	3	0			.47	3
24.63	5	4	1			.59	4	24.79	6	4	0			.80	3
57.51	6					.52	6	29.58	6	6	2	0		.60	5
84.05	5	3				.08	2	43.26	6	6	2			.25	6
86.31	6	4	3			.34	8	68.14	8	7	3			.15	8
88.56	5	3	2			.57	5	4206.74	7	7	4			.72	4
3812.41	6					.43	2	11.92	10	10	5	1		.89	20
25.82	5	4				.77	3	18.28	9	8	2			.26	5
72.30	7	5	3			.28	10	21.32	8	7	3			.29	10
92.08	5	2				.05	1	25.34	7	6	3			.31	5
98.68	7	6	3	0		.69	10	47.52	5	4				.47	2
3914.14	5	2	0			.13	2	95.18	9	6				.18	8
15.02	6	3	0			.02	4	4325.30	6	2	0			.29	3
15.75	6	3	1			.74	4	39.83	6	5	1	0		.80	3
31.67	5	5	3			.72	5	58.65	7	6	1			.60	3
42.66	6	4	0			.66	4	74.43	6	6	0			.42	3
44.85	9	9	4	1		.87	20	74.94	6	5	0				
54.69	6	4	1			.68	3	95.15	9	7	4	0		.12	3
78.70	8	8	4			.70	10	4449.92	9	9	4			.88	10
79.61	6	5				.57	3	68.34	6	5	0			.31	3

$Z\delta_7$ is accordingly entirely free from dysprosium, and $Z\delta_5$ has only faint traces of the strongest lines.

I have not yet had available a pure neoholmium, and it is therefore evident that the preparations at my disposal supplement each other in the most fortunate fashion.

An accurate separation of the lines of the components of erbium, thulium, and ytterbium[4] is not possible at present, for the reasons

[4] Auer von Welsbach has recently separated erbium and ytterbium into two components each, but nothing more precise is yet known in the matter.

given above, and there would therefore have been great danger that lines of these elements might be present in my tables for terbium. The fact that this is not the case is due to the circumstance that Urbain discovered and employed a method of fractionation in which the very considerable quantities of yttrium in the raw material separated between neoholmium and erbium. Therefore the neoholmium, and so much the more the dysprosium which separates before this, and still again the terbium separating still before this, must be free from erbium, thulium, and ytterbium. The entire absence of the very strong yttrium lines in the preparation $Z\delta_7$, $Z\delta_5$, and $Z\delta$ is, under the circumstances, an absolute proof of the absence of erbium, thulium and ytterbium from the terbium preparations. I have not failed to search among the terbium lines for the strong lines which Exner and Haschek ascribe to these elements, but with negative results, as was also ultimately the case for scandium. From this discussion it is clear that Dr. Urbain in fact has succeeded in producing terbium in a remarkable degree of purity, after it had been sought in vain for sixty years by numerous investigators of the first rank.

In the table of terbium lines which now follows, each value of the wave-length and of the intensity is the mean of three, and many times of four, separate values which were obtained in the measures of $Z\delta_7$, $Z\delta_5$, $Z\delta_1$, *Tb-Dy*8. Only in very isolated cases (chiefly for faint lines) are the figures in the table the mean from two separate values, and this only when the lines in question were present in $Z\delta_7$ as well as in $Z\delta_5$, so that it is almost certain that they belong to terbium. I measured all the lines present on the spectrograms, in so far as they could not be recognized at once as lines of carbon. The intensity 1 was assigned to the faintest lines which were still well measurable, the intenity 10 to the strongest lines. The very faintest lines which were just visible, but no longer measurable with certainty (intensity = 0), were omitted from the following table; but there were not many of them. In estimating the intensity, both the degree of blackening and the width or the whole impression of the lines were the criteria, and only in the case of diffuse lines was the intensity made to depend principally on the degree of blackening. The symbols br, dp, and r denote broad, double, and diffuse toward the red. If the assignment of a line

of terbium is not wholly free from doubt, this fact is indicated by the symbol ? following it.

In the tables I have given, along with the values of the wave-lengths and intensities found by myself, also those of Exner and Haschek for the holmium spectrum which appear to belong to terbium; and, further, those lines of gadolinium, yttrium, and dysprosium which are close to terbium lines. The values for dysprosium are also here to be regarded as only provisional.

TABLE IV

Eberhard						Exner and Haschek	
λ	Q	*Tb-Dy*8	$Z\delta_1$	$Z\delta_3$	$Z\delta_7$	λ	I
3399.06	2	0	1			3399.09	10
3416.55	1					3416.57	8
3485.02	2					3484.97	10
3515.74	1					3515.72	10
3891.21	3					3891.18	20
4045.64	1					4045.59	10
4054.05	2					4054.08	10

The study of the behavior of the separate lines gave me the following general results:

1. There are no indications of a resolution of gadolinium.

2. From Urbain's preparations there would appear to be no other element between gadolinium and terbium.

3. The terbium production by Urbain appears to be a simple body. well defined by a characteristic spectrum—an element—since there are no indications that it could be resolved.

4. The preparations made by Dr. Urbain (particularly $Z\delta_3$ and $Z\delta_1$) are pure to such an extent that a determination of the atomic weight with them must give a very nearly correct value for this constant.

5. Those lines which could be followed farthest toward gadolinium and also toward dysprosium are λλ 3523.82, 3676.52, 3703.01, 3704.05, 4005.62, 4278.71. They can serve for proving the presence of terbium in minerals and raw materials. In fact, with the aid of these I was able to find terbium in samarskite oxide and in monazite oxides free from the cerium and thorium, and in gadolinite-yttrium earths.

6. The lines of terbium are not present in the solar spectrum, or at least not with appreciable intensity.

TABLE V

Eberhard		Exner and Haschek		Remarks	Eberhard		Exner and Haschek		Remarks
Å	I	Å	I		Å	I	Å	I	
2759.65	1				2996.12	1	.12	1	
69.69	2	.65	1		99.18	3			*Gd* .20 (5)
84.63	1				3004.71	2	.70	1	
2800.66	1	.65	2	*Dy* .65(2)	05.65	4	.66	1	
09.46	3	.40	1		09.44	4	.42	1	*Gd* .47 (1)
12.79	1	.75	1		10.71	4	.70	1	
27.56	1				12.18	1			
44.08	1				13.07	1			
55.10	1				13.77	2	.81	1	
55.80	1				16.36	5	.36	dp. 1, 1	
57.84	3	.79	1		19.32	3	.27	1	
61.47	1				20.47	4	.44	1	
84.82	1	.77	1		22.10	1			
86.03	1				23.57	3			
86.42	3	.38	1		23.88	1			
87.54	1				27.46	4	.44	1	
94.58	2	.58	1		29.38	1			
97.58	5	.59	1		31.72	5	.73	1	
98.96	4	.95	1		34.22	2			*Gd* .20 (8)
2901.67	1	.70	1		35.00	1			
10.44	2	.47	2		37.14	1	.13	1	
11.96	2	.93	1		38.37	1	.40	3	*Dy* .43 (6)
14.87	4	.88	1		38.81	2	.80	1	
15.70	3	.70	1		43.74	1br			
16.37	3	.38	1		45.08	5	.06	1	
19.06	2				47.11	1			
24.28	1				51.24	5			
24.64	1				52.34	1			
26.07	1				53.41	2			
31.53	1				53.71	6	.71	2	*Gd* .70 (3)
33.02	3	.99	1		61.96	1			
33.94	1				62.90	1			
34.90	1				64.20	4	.15	1	
36.49	1				64.69	1	.67	1	
40.17	3	.13	1		65.32	1	.28	1	
41.81	1				65.82	1			
45.04	2				66.02	1			
45.84	2				67.31	5	.30	1	
46.93	1			*Dy* .95 (3)	69.14	6	.11	dp. 1, 1	
49.20	1				70.19	7	.17	2	
50.18	1	.18	1		72.79	5	.82	1	*Gd* .74 (3)
56.35	4	.32	1		76.18	2			
60.72	1				79.01	6	.99	2	
63.01	1	.00	1		80.27	1			
64.12	1	.12	1		81.68	2			
64.87	2	.85	1	*Dy* .90 (2)	82.17	1	.20	1	?*Gd* .15 (10)
68.96	3	.97	1	*Dy* .02 (2)	82.53	5	.52	1	
77.89	2	.91	1		83.94	1			
87.17	1				86.14	1			
88.81	2	.80	1		86.91	2			
92.09	1				87.66	1			*Dy* .67 (2)

TABLE V—*Continued*

Eberhard		Exner and Haschek		Remarks	Eberhard		Exner and Haschek		Remarks
A	I	A	I		A	I	A	I	
3088.55	6br	.52	1		3158.20	1			
89.25	1	.19	1	*Gd* .31 (1)	58.80	2			*Gd* .75 (1)
89.70	5	.66	2		59.35	2			
91.80	1				59.52	2			
92.13	1			*Gd* .15 (2)	62.55	2			
93.06	1				63.02	4			
93.32	1			*Dy* .25 (3)	63.95	3			
93.55	1	.56	1	*Dy* .63 (1)	64.21	3	.22	1	
93.96	1	.95	2		64.88	3			
96.97	2	.00	1	*Gd* .92 (1)	65.86	5	.87	1	
97.53	1	.52	1		67.62	4	.60	2	
3102.66	5				68.42	5			
03.10	5	.10	1		68.71	1	.74	1	*Dy* .76 (2)
09.27	2	.28	1		69.93	5			
09.93	2	.90	4	? *Dy* .89 (6)	71.30	2			
12.53	1				72.04	1			
12.68	1				73.84	4			
13.72	4				73.94	1	.90	2	
14.56	1				74.76	5	.80	1	
17.37	2				75.55	1			
18.01	2	.02	2	*Gd* .07(1), *Dy* .04 (4)	76.90	1			
					77.15	1			
19.73	4	.71	1		77.61	1br	.66	1	*Dy* .63 (2)
21.55	1	.55	1		79.94	1			
22.06	3	.07	1		80.66	6	.72	1	
22.93	3				81.30	1			
23.16	4	.17	1		82.91	1			
24.12	2			*Gd* .16 (3)	83.39	3	.34	1	*Dy* .32 (3)
24.65	1				83.76	3			
29.00	1				83.98	3	.01	1	
30.78	1br				85.67	2			
31.48	3				86.33	2			
34.37	4	.39	1		87.37	6	.39	2	
35.41	2			*Dy* .51 (6)	88.15	6	.18	1	
37.40	2				88.68	2			
38.75	1			*Gd* .81 (1)	89.87	1	.92	1	*Dy* .90 (2)
39.77	6	.74	1		90.10	2			
40.18	4	.15	1		90.80	1br	.80	1	*Dy* .76 (2)
43.56	1				92.58	1	.09	1	
44.56	1	.60	1		93.13	1			
45.33	4	.31	2	*Dy* .32 (3)	94.31	2			
46.35	2				94.83	4			
46.83	2				95.74	5			*Y* .75 (3)
47.07	4	.02	1		98.15	1			
47.27	4	.25	1		99.67	7	.65	1	*Gd* .67 (1)
48.84	4	.85	1		3200.84	3			
54.85	1				02.06	1			
55.22	1				02.82	2			?
55.74	3				03.15	2			
57.28	1	.30	1	*Dy* .31 (2)	07.19	3	.23	2	*Dy* .25 (6)
57.62	1	.64	1	*Dy* .66 (2)	07.63	4			

TABLE V—*Continued*

Eberhard		Exner and Haschek		Remarks	Eberhard		Exner and Haschek		Remarks
Å	I	Å	I		Å	I	Å	I	
3208.09	3				3262.83	3			
09.66	3				63.09	5	.10	1	
10.15	1				63.87	1			
10.32	3				64.05	3	.03	1	
15.15	3				64.19	1			
15.63	1				65.05	3			
19.04	8	.05	2		66.09	2	.12	1	
20.09	6	.10	2		66.55	6	.52	1	
20.34	1				68.26	4	.20	1	
23.10	3				68.65	3	.66	1	
24.84	1				70.70	1br			
25.63	1			*Gd* .57 (2)	70.83	1			
27.10	1				72.53	4	.48	1	
27.61	1				73.28	2			
29.30	2				74.31	3			*Gd* .30 (1)
29.81	1br				74.45	2			
30.13	4				75.84	1	.87	1	*Dy* .92 (2)
30.85	1				77.45	3	.45	1	
31.18	3	.17	1		77.85	1br			
31.59	1				79.22	1			
32.16	2				80.44	6	.40	2	
33.69	1				81.55	6	.55	1	
34.62	2				83.26	6	.27	1	
35.88	3			*Dy* .97 (6)	83.96	1			
36.29	2			*Gd* .26 (1)	85.16	5	.16	1	
39.39	1				85.33	3			
39.74	2br	.69	1		86.29	1	.30	1	
40.11	5	.14	1		87.08	1br			
40.78	4				87.70	3	.67	1	
42.06	1				91.69	4	.68	1	
43.32	3				93.20	4 1	.18	2	
44.74	1				94.16	4			*Gd* .21 (2)
45.31	3			*Dy* .25 (5)	95.44	2	.50	1	
45.52	1				98.34	2	.34	1	
46.64	1				98.79	4	.76	1	
47.32	1				3304.22	2	.19	1	
47.98	1				04.39	2	.45	1	*Dy* .42 (2)
49.75	2				05.07	3	.09	2	
50.63	1				05.51	2			*Dy* .55 (2)
50.88	1				07.53	5br			
51.06	1				07.92	1			
51.37	4	.42	5	*Dy* .41 (7)	08.66	2			*Gd* .66 (1)
52.44	6	.45	1		09.28	2			
53.68	1				10.24	1			
55.34	2	.36	1		10.49	1			
58.53	1				10.92	2			
59.54	4	.51	1		12.70	1			
60.23	4			*Dy* .12 (6)	12.90	3	.86	3	
60.80	1	.84	2	*Dy* .83 (4)	14.45	3			
60.97	2				15.17	1			
61.86	5				17.71	2			

TABLE V—*Continued*

Eberhard		Exner and Haschek		Remarks	Eberhard		Exner and Haschek		Remarks
λ	I	λ	I		λ	I	λ	I	
3318.17	1			*Gd* .19 (1)	3375.18	4	.16	1	
19.31	1				76.51	2	.47	1	*Dy* .50 (3)
19.93	1br			*Dy* .02 (5)	76.79	3	.74	1	
21.02	1				77.80	4			
21.25	4br	.23	1		78.86	4			
22.38	5	.40	1		79.02	4	.00	2	
23.52	3				79.32	1			
24.03	3	.06	1		80.78	4	.79	1	
24.54	8	.56	4		81.01	2			
25.04	3	.64	1		81.74	1	.70	1	
27.24	3	.20	2		82.91	4	.91	1	
29.20	5	.20	1		86.61	4			*Dy* .70 (3)
33.33	3	.30	1		87.77	1			
34.07	2				88.51	1	.48	1	
34.47	1				89.72	2			
34.62	3	.56	1	*Dy* .56 (1)	90.15	3			
35.56	2				90.78	1			
36.87	5	.90	1		91.05	1			*Gd* .04 (1)
38.18	3	.14	1		91.39	3			*Gd* .45 (1)
39.15	5	.14	1		91.80	1			
39.75	2				92.20	2			
43.10	1				93.12	1	.10	1	
43.71	1	.69	2	*Dy* .65 (1)	93.68	2			*Gd* .76 (2), *Dy* .71 (7)
43.90	1								
45.00	1				94.94	3	.97	1	
46.49	1	.45	1		95.35	3			
47.41	3	.36	1		97.36	1			*Gd* .35 (1)
48.25	3	.20	1		97.76	2			
48.43	1				98.49	4	.45	1	
48.70	3	.70	1		98.69	1			
49.57	6	.54	1		99.23	3			
50.64	2			*Gd* .63 (8)	3400.10	2			*Gd* .12 (3)
51.58	1				00.64	3	.62	1	
53.05	3				00.99	4	.01	1	
57.50	3			*Dy* .46 (1)	02.45	4			
59.47	1				04.91	3			
59.99	2				06.16	3			
60.39	2				07.25	1	.30	2	*Dy* .31 (2)
62.32	5			*Gd* .40 (8)	09.00	1			
64.33	2			*Gd* .36 (2)	10.04	1			
64.48	1				10.56	3			
65.01	7	.01	1		10.83	3	.85	2	
65.42	3				13.92	5	.92	5	*Dy* .94 (7)
66.31	1	.33	1		15.59	1			
67.31	3	.30	1	*Gd* .22 (1)	16.40	4			
68.67	1				16.71	1			
70.73	3	.70	1		17.87	2			
71.65	3	.65	1		18.11	1			
72.50	4	.50	1		20.47	5	.46	1	
72.85	1	.90	5	*Dy* .88 (3)	23.21	1			
74.56	3				23.56	1			

TABLE V—*Continued*

Eberhard		Exner and Haschek		Remarks	Eberhard		Exner and Haschek		Remarks
λ	I	λ	I		λ	I	λ	I	
3424.14	2			*Gd* .07 (5)	3468.55	1	.55	2	*Dy* .58 (2)
24.46	1				69.84	1			
24.83	1				70.01	1	.00	1	*Dy* .06 (1)
25.57	1				70.52	3	.46	1	
26.06	2			*Gd* .08 (3)	71.87	3			
26.48	2			*Gd* .46 (2)	72.52	3	.49	1	
28.29	1	.26	2		72.95	6	.95	1	
28.87	1				73.18	2			
29.24	1	.26	1		73.94	2			*Dy* .84 (3)
29.92	1				75.46	1br			
30.31	1				76.28	2			
30.49	1				76.45	2	.47	1	*Gd* .45 (2)
30.76	4				79.40	1			
32.03	1				80.33	4	.32	1	
32.51	3				80.63	1dp	.57	1	
33.38	5	.40	1		81.69	2			
34.57	2	.51	5	*Dy* .50 (6)	82.98	2	.91	1	*Dy* .93 (3)
35.08	1				83.20	3	.16	1	
35.70	1				83.85	3	.83	1	
36.27	1				84.86	1br			*Dy* .84 (2)
37.12	3	.06	1	*Dy* .07 (1)	87.43	3			*Dy* .38 (2)
38.73	3				87.78	2			*Dy* .72 (3)
39.22	1				88.96	1			
39.87	2	.86	1	*Gd* .93 (3)	89.65	4	.63	1	
40.55	4	.55	1		89.91	2			
41.84	1			*Gd* .92 (2)	90.42	1			
44.06	1				91.41	2	.39	1	
44.74	3	.70	1		91.94	1			
44.91	1				92.13	2br	.13	1	*Gd* .10 (6)
46.52	5	.46	1		92.69	3	.66	1	
49.02	1				93.14	2			
49.61	2				94.39	2			
52.56	2				95.53	2			
53.01	1				96.43	1	.46	3	
53.60	1				98.90	1	.82	3	*Dy* .86 (3)
54.24	3			*Gd* .30 (3)	99.47	1dp			
55.55	1				3500.20	1			
56.15	2	.13	10	*Dy* .13 (3, very broad)	00.42	3			
					00.99	5	.96	1	
56.71	1	.68	4	*Dy* .67 (6)	04.18	1			
57.18	3			*Gd* .17 (2)	04.91	2			
58.77	3	.73	1		05.26	1	.24	dp1,1	
60.57	3	.54	2	*Dy* .54 (2)	06.05	3			
61.14	4	.10	5	*Dy* .10 (5)	07.58	3	.60	1	
62.68	1				09.32	10	.30	8	Perhaps double
62.98	1								
63.12	2			*Gd* .14 (3)	10.25	2	.22	1	*Gd* .26 (1), *Dy* .28 (2)
64.76	1br								
66.13	2				11.21	1	.15	1	
67.03	2			*Gd* .09 (3)	12.73	2	.70	2	*Gd* .66 (4), *Dy* .70 (3)
68.17	5	.15	1						

TABLE V—*Continued*

Eberhard		Exner and Haschek		Remarks	Eberhard		Exner and Haschek		Remarks
Å	I	Å	I		Å	I	Å		
3513.24	4	.20	1		3571.49	1			
14.01	1				72.25	2	.28	1	
14.31	1	.27	1		75.77	1dp			
15.16	3	.16	1		76.03	2			
15.64	2				76.78	1	.74	1	
16.31	2				77.21	3			
16.79	1				79.36	5	.33	1	*Dy* .27 (2)
19.91	4				85.24	2	.21	5	*Dy* .22 (3)
20.95	2	.96	1		87.60	3	.56	1	
23.10	1	.02	2	*Dy* .02 (2)	87.86	1	.90	1	*Y* .86 (1)
23.33	1				89.74	1			
23.82	7	.81	2		91.55	2	.58	4	? *Gd* .56 (2), *Dy* .57 (6)
25.27	3	.27	1	*Gd* .28 (1)					
25.79	3	.81	1		91.78	2			
26.02	1				93.23	3br	.29	1	
26.91	1				93.88	2	.85	1	
29.93	2				94.41	2	.42	1	
30.57	1	.57	1	? *Dy* .57 (1)	94.73	1	.75	1	
32.00	2				95.12	3			*Dy* .20 (5)
32.84	2				96.52	5	.52	1	
33.79	2				96.97	1			*Gd* .99 (1)
33.99	2				97.96	1			
36.51	3				98.21	3			
37.32	1				3600.19	2			
37.88	1			*Dy* .83 (2)	00.55	6	.50	4	*Dy* .56 (4)
38.03	3				00.94	1			
39.05	2				01.68	1	.65	1	
39.97	1				01.86	2			
40.41	5	.41	1		02.64	1			
43.38	3				05.04	4	.04	1	*Gd* .00 (4), *Dy* .04 (1)
44.03	4								
44.54	1			? *Dy* .54 (3)	06.14	2			
46.64	2				06.31	3	.26	5	*Dy* .28 (6)
51.14	1dp				07.66	1			
52.12	3	.17	1	*Dy* .19 (2)	08.00	1			*Gd* .01 (1)
55.42	3				08.35	1			
55.87	1	.83	1	?	09.20	1			
56.24	1				09.70	1dp			
56.39	1				10.00	1			
58.91	1br				11.42	3			
59.39	1br	.42	2	?	11.61	3			
59.54	2				13.17	3	.21	2	*Dy* .22 (3)
59.88	3				13.47	1			
61.88	6br	.83	3		13.81	3	.80	1	
63.05	3	.09	1		14.79	3	.77	1	*Dy* .86 (2)
65.87	3	.84	2		15.58	1			
66.25	1	.23	1	*Dy* .21 (1)	15.77	4br	.76	1	
67.50	5	.50	2		16.71	4	.70	2	
67.99	1				18.01	5	.98	1	*Dy* .95 (3)
68.64	8	.63	4		18.31	2	.25	2	*Dy* .23 (4)
69.11	5	.14	2		19.86	4	.85	1	

TABLE V—*Continued*

Eberhard		Exner and Haschek		Remarks	Eberhard		Exner and Haschek		Remarks
λ	I	λ	I		λ	I	λ	I	
3622.27	2	.25	1		3668.14	1	.11	1	
24.02	4				68.64	1	.66	1	*Dy* .69 (1)
24.89	3				69.79	1	.79	1	
25.66	6	.64	2		70.80	1			
26.27	1				71.52	2			
26.63	5	.61	1		72.51	2			*Dy* .45 (6)
27.01	2			*Gd* .02 (1)	75.91	2			
28.31	3br	.35	1		76.52	8	.48	3	*Dy* .58 (1)
28.87	1			*Y* .85 (4)	78.04	3			
29.59	4br			*Gd* .66 (2), *Dy* .57 (5)	78.94	2			
					81.62	1			
30.40	3	.35	5	*Gd* .39 (1), *Dy* .39 (6)	82.45	7	.45	2	
					83.44	1			
31.20	2			*Dy* .20 (1)	84.99	2	.00	1	
31.64	4				87.34	1			
33.43	6			*Dy* .41 (2)	88.32	5	.30	1	
35.58	3				89.28	4	.24	1	*Dy* .18 (1)
38.59	4	.58	1	*Dy* .64 (3)	89.88	2			
39.06	1	.03	1	*Dy* .05 (1)	91.32	7br	.32	2	
39.95	4	.99	1	*Dy* .00 (2)	92.15	1			
40.91	1	.95	1	*Dy* .97 (3)	93.00	4			
41.80	6	.77	1		93.74	2	.73	1	*Gd* .76 (1)
42.19	1				94.87	1			
42.50	1				96.45	3	.40	1	
42.82	3				97.03	4	.05	2	
43.43	2				97.91	1			? *Gd* .89 (5)
43.90	1				90.50	4			
44.28	2				3700.28	1			
45.96	3	.96	1	*Dy* .00 (5)	00.47	1			
46.28	1			*Gd* .36 (15)	01.47	1			
46.58	1				03.01	8	.99	4	
47.19	4				03.64	1			
47.87	4				04.05	8	.05	3	
49.51	1				05.25	2			
50.55	7	.51	3	*Dy* .57 (2br)	06.54	4	.53	1	
51.08	3	.10	1	*Gd* .09 (2)	08.93	3			
52.03	3	.00	1		09.51	4			
52.43	2	.41	1		11.92	8br	.90	2	*Dy* .81 (5)
53.11	3				14.56	1br			
54.02	2	.00	1	? *Dy* .02 (2)	16.24	2			
55.01	5	.99	2	*Dy* .02 (3)	16.58	2	.54	1	*Gd* .52 (5)
56.63	1			*Dy* .58 (1)	17.07	1	.05	2	*Dy* .10 (3)
56.90	1				17.64	3			*Gd* .60 (4)
58.42	2			*Gd* .35 (1)	18.06	1			
59.01	6dp	.00	3		18.65	2			
59.58	3				19.62	3			*Gd* .63 (10)
60.62	2				20.46	1			
60.89	3	.85	1		20.59	1			
63.27	5	.25	1		22.79	2	.79	1	
64.45	1				23.26	3			
65.75	1				25.11	2			

TABLE V—*Continued*

Eberhard		Exner and Haschek		Remarks	Eberhard		Exner and Haschek		Remarks
λ	I	λ	I		λ	I	λ	I	
3725.59	2br	.59	1	*Gd* .63 (3), *Dy* .62 (1)	3793.69	3	.70	2	
28.83	2	.88	1		94.50	1br	.51	1	
29.12	3				98.01	1			
30.07	5	.05	1		98.66	3	.70	1	
30.57	1				99.09	1			
32.00	1				99.72	3			
32.54	5	.53	1		3801.06	2			
34.88	2				02.33	2			
35.17	2			?	06.53	1			*Dy* .47 (4)
38.57	1br				07.00	3	.00	2	
39.06	2				11.82	2			
40.51	3				12.84	2	.83	1	
41.35	4	.32	2		13.28	1			*Dy* .27 (2)
41.76	3				16.33	1br	.31	3	*Dy* .35 (3)
42.04	3	.02	1	*Gd* .05 (1), *Dy* .02 (2)	20.26	1			
					20.55	1			
43.27	3	.21	1	*Dy* .24 (2)	20.93	2			
45.20	3	.17	2		23.23	1			
46.72	3				24.51	2	.50	2	
47.33	4	.33	1		42.61	4			
47.52	6	.48	1		43.16	3			
48.97	1				44.39	1			
49.47	1				48.91	4			
49.88	1				52.02	1			
51.81	1br				74.30	6	.25	10	*Dy* .34 (4)
52.37	1br			*Gd* .42 (1)	85.27	1	.23	1	
53.74	2				86.18	1			
55.38	6	.35	2	*Gd* .38 (1)	87.00	3	.96	1	
57.58	3			*Dy* .52 (6)	87.85	2			*Gd* .87 (1)
58.06	4				88.40	2	.37	1	
58.46	1			? *Gd* .46 (5)	90.03	1			
59.53	3br	.50	1		93.52	3			
60.34	1				94.73	1dp			
61.25	1				96.16	3			
62.88	1	.89	1		96.74	4	.78	1	
65.26	6	.28	2		97.45	1			
67.65	3			*Dy* .74 (2)	98.03	3	.01	1	
75.41	2				99.34	8	.32	3	
76.62	7				99.72	3	.77	1	
77.63	2	.57	2	*Dy* .59 (3)	3900.92	1			
79.36	2			*Dy* .32 (2)	01.47	3	.47	2	
80.14	1				01.79	1			
81.80	1				02.14	1br			
83.62	3			*Dy* .67 (5)	03.29	1			*Dy* .23 (1)
85.52	1	.54	3	? *Dy* .54 (3)	04.33	1	.35	2	*Dy* .38 (3)
87.35	4			*Y* .31 (2)	04.72	1br			
89.20	1				05.72	1	.73	3	? *Si* .69 (10), *Dy* .69 (2)
89.86	1				06.71	1			
90.06	2				08.23	3	.17	1	
92.35	1				08.82	2			

TABLE V—*Continued*

Eberhard		Exner and Haschek		Remarks	Eberhard		Exner and Haschek		Remarks
λ	I	λ	I		λ	I	λ	I	
3909.30	4	.28	1		3956.29	3			
09.69	4	.71	1		57.49	2			
10.31	2	.28	1	*Dy* .24 (1)	58.11	4	.11	2	*Dy* .19 (4)
10.56	1				58.49	6	.52	1	
10.78	1			*Dy* .70 (1)	58.76	1			
11.01	2				60.28	1br			*Gd* .27 (1)
12.42	1				60.84	2			
12.93	2dp			*Dy* .00 (2)	62.12	1			
13.62	2				62.76	1	.75	2	*Dy* .74 (2)
13.93	1			*Gd* .92 (1)	63.06	1			
14.72	2				65.25	2	.25	1	*Dy* .26 (1)
15.54	5	.57	1		66.09	4			
17.11	1				67.36	3			
17.45	2	.48	3	*Dy* .49 (2)	67.80	2			
18.97	2				70.35	4	.36	1	
19.67	7r	.64	1		71.90	3	.90	1	*Gd* .91 (4)
20.11	2				72.22	2	.24	1	
20.88	4				73.07	1			*Dy* .18 (1)
21.16	1				74.41	4	.47	1	
21.91	1				74.84	2	.86	2	
22.23	5	.25	1		76.99	10	.00	5	
22.88	5	.92	1		80.41	1			
23.13	1				81.29	5	.32	1	
24.53	2			*Dy* .60 (2)	82.02	10	.09	8	*Dy* .10 (7)
24.95	2				82.47	1	.47	1	
25.57	7	57	2		84.00	3			
29 94	2dp			*Dy* 86 (1)	84.18	3			
30.95	3				84.96	1			
32.50	2br				85.22	2			
35.38	7r	.35	2		86.48	3	.49	1	
37.30	1	.30	1	*Dy* .32 (1)	87.84	1	.78	1	
37.77	2	.74	1		89.63	1			
39.68	8	.68	2		90.75	3			
41.32	3	.34	1		91.73	1			
41.53	1				92.33	1			
42.34	3	.34	1		93.00	1			
43.07	1				93.67	4			*Dy* .71 (2)
43.81	2				95.27	1			
44.36	1				95.93	1	.94	1	*Dy* .91 (1)
45.07	2br				97.52	3			
47.02	6	.05	3	*Dy* .09 (5)	98.24	1	.20	2	*Dy* .20 (1)
48.45	4	.46	1		98.53	3			
49.67	1				99.03	2	.05	1	
50.05	1				99.50	4	.55	1	
50.27	2				4000.13	4	.13	1	
50.55	3			*Y* .52 (10), *Dy* .52 (5)	01.40	1	.45	1	*Gd* .40 (3)
					02.30	5br	.31	1	*Dy* .35 (1)
50.91	1				02.70	7	.72	2	
52.02	1				03.91	2	.92	1	
54.18	4	.17	1		04.03	1	.00	1	
55.89	1br	.83	1		04.64	2	.59	1	

TABLE V—*Continued*

Eberhard		Exner aed Haschek		Remarks	Eberhard		Exner and Haschek		Remarks
Å	I	Å	I		Å	I	Å	I	
4005.62	8	.64	3		4061.74	5	.70	2	*Dy* .69 (1)
06.07	3			*Dy* .01 (1)	62.36	1			
07.32	1	.28	1	*Dy* .30 (1)	62.94	1			
07.86	1	.89	1	*Dy* .91 (3)	64.02	4	.97	1	
09.34	2	.30	1	*Gd* .35 (2)	66.33	5	.33	1	
09.65	3				70.25	3	.25	1	*Dy* .24 (1)
10.18	2	.21	2	*Dy* .23 (3)	70.69	2			
12.94	5	.92	2	*Dy* .97 (1)	71.36	2			
13.36	3	.40	1		72.44	2			*Dy* .46 (1)
15.66	1br				72.84	4			*Dy* .76 (1)
16.09	1dp				73.88	3	.86	1	*Gd* .99 (10)
16.44	1br				74.12	1	.13	2	*Dy* .14 (2)
17.01	1	.00	1	*Dy* .06 (1)	74.22	1dp			
17.99	1br			*Dy* .92 (2)	75.32	3	.32	1	
18.51	1dp				75.99	1			
19.28	5	.25	1		78.59	2			*Gd* .60 (6)
20.60	5	.62	3		80.94	1			
21.25	2				81.38	4	.38	2	
23.02	3	.03	1		82.37	2			
23.87	2	.85	2	*Dy* .89 (3)	82.95	2			
24.21	3				83.35	2			*Dy* .26 (1)
24.88	3				83.81	2			*Gd* .87 (2), *Dy* .75 (1)
25.84	4			*Dy* .78 (2)					
27.54	1br				84.40	2	.40	1	*Dy* .43 (1)
28.13	1				84.99	2			
28.42	5	.45	3	*Dy* .51 (5)	86.77	3	.75	1	
30.11	1				87.85	2			*Gd* .85 (3), *Dy* .94 (2)
31.77	6	.78	2						
32.45	5	.48	2		89.48	3	.50	1	
33.18	7	.20	3		89.66	2	.64	1	
36.35	1				91.49	1			
36.57	1			*Dy* .51 (4)	92.34	3	.34	1	
38.98	2			*Dy* .01 (2)	94.20	1			
39.35	2				94.58	6			
39.64	2	.63	1	*Gd* .63 (1)	96.09	1			*Dy* .25 (2)
40.26	1				97.56	2dp			
40.56	3				99.32	1			
42.00	1			*Dy* 12. (5)	99.62	2			
42.47	2				4101.08	5br			
43.81	2br			*Gd* .85 (1)	01.82	4			
47.32	3				02.67	3			
48.97	1	.96	1		03.60	4			*Dy* .48 (9)
51.65	1				04.09	6			*Dy* .00 (4)
51.95	4	.95	2	*Dy* .95 (2)	05.54	3	.50	1	
52.56	1				06.17	1	.12	1	?
52.99	6	.96	1		07.90	1br			
54.22	3				09.70	1			
57.18	1				12.66	3	.68	1	
58.59	2				13.05	3			*Dy* .18 (1)
60.54	4	.53	1		14.27	3	.21	2	*Dy* .23 (2)
61.01	5	.00	1		15.49	2br	.46	1	*Gd* .54 (1)

TABLE V—*Continued*

Eberhard		Exner and Haschek		Remarks	Eberhard		Exner and Haschek		Remarks
λ	I	λ	I		λ	I	λ	I	
4116.68	1		*		4185.10	2			
17.40	1				86.38	2			
20.09	3	.12	1		87.33	3			
20.69	2				88.27	2			*Gd* .20 (2)
21.19	1				88.68	3			
22.38	1				90.28	1			
22.66	2				91.80	3	.83	5	*Gd* .75 (2), *Dy* .81 (3)
23.93	1			*Dy* .88 (1)					
26.90	1				93.29	1			*Gd* .29 (1)
27.44	3				93.55	1			
30.32	1				93.94	1			
31.28	1			*Dy* .18 (3)	94.14	1			
31.63	3	.65	1	*Gd* .65 (3)	96.91	3			
33.01	2	.03	2	*Dy* .02 (2)	97.27	1			*Gd* .21 (3)
35.55	3	.53	1	*Gd* .60 (1)	98.61	2			
38.79	1			*Dy* .70 (1)	99.87	1			
39.22	2				4200.83	2			
39.94	3				01.18	6	.15	1	
40.93	1	.95	1		03.91	4	.88	1	
41.71	4	.67	4	*Dy* .67 (6)	06.65	1			*Dy* .70 (6)
42.61	1				07.06	1			
43.76	3				07.67	2			
44.55	8	.58	3		08.83	3			
47.13	1				13.62	4			*Dy* .76 (2)
48.34	1				14.56	4	.55	1	
49.30	3	.30	1		15.25	4	.32	5	? *Gd* .13 (6) *Dy* .30 (5)
50.71	2								
51.28	1	.26	3		16.11	1	.06	1	
53.65	1			*Gd* .69 (2)	16.83	1			
56.44	3				17.66	3			
58.46	1				18.06	1			
58.70	2				19.01	1			
61.64	1br				19.32	3			
66.69	1				20.24	3			
69.27	3				22.85	1			
69.50	1	.45	1	*Dy* .40 (2)	23.46	3			
70.07	1				24.43	3			*Y* .43 (1)
70.65	2	.71	1		26.63	9br	.58	1	
71.21	3				30.74	2			
71.94	5			*Y* .91 (2), *Gd* .86 (2)	31.54	2			
					32.05	3			*Dy* .18 (5)
72.77	3				32.36	3			
73.00	1				32.98	4			
73.64	4				34.37	1			*Dy* .33 (1)
76.04	1				34.80	1			
79.14	2				35.52	2	.54	1	
79.97	1				39.44	3			
80.54	4				40.11	1			*Dy* .01 (5)
81.03	3	.07	1	*Gd* .05 (2)	40.33	1br			
81.50	3				42.43	1			
84.49	2			*Gd* .48 (10)					

TABLE V—*Continued*

Eberhard		Exner and Haschek		Remarks	Eberhard		Exner and Haschek		Remarks
Å	I	Å	I		Å	I	Å	I	
4242.73	3				4315.87	2			
44.73	1				19.05	9	.01	3	
45.36	1				20.45	1			
45.95	1			*Dy* .07 (4)	22.39	5	.40	2	*Gd* .35 (2)
46.77	2			*Gd* .70 (3)					*Dy* .37 (1)
48.73	1			*Dy* .65 (2)	23.04	3			
50.44	2	.50	1	*Dy* .55 (1)	23.83	3			*Dy* .95 (2)
51.50	2				26.00	9	.04	2	
51.88	6	.85	1	*Gd* .90 (10),	26.64	6	.62	3	*Dy* .58 (2)
				Dy .94 (1)	29.10	5	.08	2	*Gd* .06 (1)
54.17	1								*Dy* .08 (4)
55.39	7	.36	1		30.53	1			
56.30	1				32.30	5	.30	1	
58.37	8	32	2		34.84	2			
60.94	1				36.66	7dp	.64	2	
63.85	1			*Dy* .75 (1)	37.79	5	.82	1	
64.82	1				38.62	6	.60	3	
65.15	1				40.79	6	.79	2	
66.53	5	.49	1		42.70	9br	.73	1	
69.49	1				48.49	2	.51	1	*Dy* .52 (1)
69.87	6	.87	1		49.78	2			
71.73	1				50.92	2	.93	2	
72.44	2				51.80	1dp			
73.38	2			*Dy* .33 (2)	53.39	9	.35	1	
75.39	4	.36	1		56.28	4	.25	1	
76.91	8br	.86	3	*Dy* .88 (4)	57.01	7	.99	2	
77.93	3				60.31	5	.35	1	*Dy* .36 (2)
78.71	10	.67	4		66.18	1			*Y* .20 (1)
80.67	1			? *Gd* .69 (8)	67.67	5			
81.48	1				72.22	2	.23	1	
85.30	5	.30	1		76.59	3			
85.92	2	.98	1	*Gd* .96 (2)	81.47	2			
86.29	1			*Gd* .26 (2)	82.60	5	.61	1	
87.06	3	.05	1		84.24	1			
89.89	4	.87	1		85.85	4			
94.53	1				86.24	5	.21	1	
95.50	1				88.42	4	.43	1	
96.49	3			*Gd* .46 (3)	89.20	1			
98.55	4			*Gd* .60 (1)	91.10	5			*Gd* .12 (3)
4300.08	4	.05	1		94.20	2			*Y* .23 (1)
01.11	1			?	96.75	5			
03.12	4			*Dy* .17 (3)	4400.97	1			*Gd* .93 (1)
04.17	2				01.72	3			
07.38	3	.35	1		03.36	5			*Gd* .30 (4)
08.85	7	.80	10	*Dy* .82 (7)	05.58	5			
10.61	4	.56	1		09.68	4br			*Dy* .55 (8)
11.17	1	.16	1	*Gd* .14 (2),	16.43	5			
				Dy 18 (1)	20.38	2			
11.74	2	.72	1		23.28	5	.27	1	
12.26	3			*Dy* .15 (1)	24.64	1			
13.40	2	.40	1		27.85	2			

TABLE V—*Continued*

Eberhard		Exner and Haschek		Remarks	Eberhard		Exner and Haschek		Remarks
λ	I	λ	I		λ	I	λ	I	
4428.50	1				4503.75	1			*Dy* .79 (1)
30.27	1br				04.72	1			
30.88	1			*Gd* .82 (5)	09.20	5			
32.88	3				11.68	5			
34.63	5				13.12	3			
35.17	2			*? Ca*	14.47	3			
35.73	3				16.07	1			
36.27	5	.24	1		19.92	1dp			
39.12	4				24.52	1			
39.53	2				25.14	1			
41.42	1			*Dy* .35 (1)	26.08	1			
41.67	1				29.03	1			
48.20	3				29.91	2			
51.79	2				30.75	1			
52.96	2br				31.98	1			
53.31	1				34.33	2			
55.07	1			*? Ca*	37.10	4			*Gd* .11 (1)
58.65	1				37.38	3			
59.57	3				40.74	1			
61.43	1				46.63	1			
62.38	1br				47.64	1			
65.88	1				48.52	1			
67.87	2				49.26	3			
69.29	1				49.90	3			
69.56	1				50.61	3			
69.90	1br				51.10	1	.06	1	*Gd* .15 (1)
71.34	1	.31	1		56.65	3	.63	1	*Dy* .66 (2)
71.89	2				57.07	1			
73.00	1				57.45	1			
73.46	1			*Gd* .45 (1)	62.41	4			
4473.87	1				63.87	6			
85.85	1				65.04	1			
88.33	2				73.34	2			
89.93	2				78.88	6	.88	1	
90.84	1				80.55	2			
91.19	1				85.01	2			
93.25	7	.26	1		91.73	2			
4501.47	1			*Dy* .44 (1)					

By the settlement of the terbium question an important step has been made in the investigation of the yttrium earths, and it will now be possible for the first time to successfully undertake the discussion of the further earths of this group, dysprosium and neoholmium. I hope before long to be able to give complete tables of wave-lengths for the first of these elements, based again upon preparations from Dr. Urbain.

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ON THE RELATION BETWEEN STELLAR SPECTRAL TYPES AND THE INTENSITIES OF CERTAIN LINES IN THE SPECTRA

By SEBASTIAN ALBRECHT

During the past summer, in connection with the measurement of the spectrograms obtained at the Mills Observatory in Chile by Professor Wright, assisted by Dr. Palmer, an investigation of the individual spectrum lines was begun, with a view of determining whether there is a shift of any of the lines which is progressive from spectral type to type. Several lines were found which undergo such a progressive change as indicated by the radial velocities obtained from them, this being especially noticeable for the line λ 4468.663.[1] Since then, several lines which were formerly not measured have been included in the observing list, largely for the purpose of studying their behavior in the different types of spectra, rather than for use in the radial velocity determinations. An examination of Rowland's tables shows that in most, but not all, cases studied, lines apparently single are in reality blends of two or more close components. The nature of the variations found is such as to indicate varying intensities of the same components, rather than the presence or absence of different components in the different types. It was the intention, when sufficient data had been obtained, to make comparisons with the enhanced and weakened lines in the spark and arc spectra. When a list of sun-spot lines[2] in the region covered by the southern Mills plates became available, a comparison with these was made instead, and the preliminary results are given in this paper. The investigation was limited to stars of types F to Mb inclusive on the Harvard classification. In this classification the Sun is of type G.

The principal result of the comparison is the very strong indication that the physical conditions in the stars as we pass from the F to the Mb type vary roughly in the same direction as from the Sun

[1] In preparing this manuscript I note that Slipher has called attention to the fact that this line gives too large positive velocities in *α Boötis*.

[2] Walter S. Adams, "Sun-spot Lines in the Spectrum of *Arcturus*," *Astrophysical Journal*, **24**, 69, 1906.

to the sun-spots. It is not intended to convey the impression, however, that any one type has been found in which the conditions are exactly the same as in the sun-spots, though an early K type is probably nearest to it. In the Mb type the relative intensities of the lines, as shown both by their appearance and their residuals, have gone far beyond what they are in the Sun, whereas in the F type they much precede the condition in the solar spectrum. Adams (*loc. cit.*) has shown a striking similarity to exist in the intensities of sun-spot lines and of the corresponding lines in the spectrum of *Arcturus* (type K), while Hale and Adams[1] have made a similar comparison of intensities for *α Orionis* (type Ma) in the region λ 5393 to λ 5703.

A large number of lines might be mentioned which change greatly in intensity and appearance as we proceed from the F to the Mb type, this change being frequently very prominent even from the G to the K type, and which are not included in Adams' list of lines affected in sun-spots. Among the most striking of these are the *Cr* lines, λ 4254.5 and λ 4274.9, which become very strong, wide, and diffuse as we follow the scale of stellar types. A few cases of contradictory evidence have also been found, in which the residuals show a definite and decided shift in the opposite direction from that which would be expected from the intensities assigned to the components in sun-spots. Among these the line λ 4435.2 may be especially mentioned. For this blend both my value of the wavelength, as determined from the spectrograms, and the progressive trend of the residuals indicate a shift of its center toward the violet instead of toward the red. In one or two cases also the residuals tend to show an oscillation of the line, in one direction from the F to the G (or early K) type, and in the opposite direction from the G to the Mb type. Some of the observed differences between sun-spots and stellar K types, in which the physical conditions may be similar, may be due to the fact that in the stars this condition is the average condition in their entire atmospheres, while in the case of the sun-spots some effects may be altered by overlying layers of gases and vapors or by other local circumstances. Nevertheless the similarities are sufficiently striking to promise much for this line of study. The results here given depend not only upon the appearances

[1] *Astrophysical Journal*, **23**, 400, 1906.

of the lines, but primarily upon quantitative measurements of their positions.

It is possible that for variable stars of large light-changes, some traces of velocity variations may be found, corresponding to small changes in spectral types from maximum to minimum. Spectrograms for a few cases are available and they will be examined.

Dr. Palmer made a simple tabulation of the residual velocities, without regard to spectral type, for a large number of lines in the spectra measured by himself, for the purpose of improving the wave-lengths of the lines used. The values in the old tables had been obtained by blending the components according to the intensities in the Sun assigned to them by Rowland. The wave-lengths credited to him in this paper are the average wave-lengths, deduced by him, for these lines in all the stars measured. In the case of three lines he found two values each. For one of the three lines, one value was for the types G, K, M, and the other for types A and F, while for the other two lines one value related to the types F, G, and K, and the other to the types K5M and Mb.

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In the tables following the residuals are given in kilometers. The capital letter at the head of each column denotes the stellar type. The intensities for the Sun are from Rowland's tables, while those for sun-spots and for *Arcturus* are from Adams' article (*loc. cit.*), where n.c. = not affected.

	Element	Intensities	
		In Sun	In Sun-spots
λ 4258.219		1 N	
.477	*Fe*	2	3–4

In the F type this blend is strong, of nearly average width, and has sharp edges. In the G type it is broad and somewhat fuzzy, the widening having occurred toward the longer wave-lengths. In the Mb type the edges are usually sharp.

My residuals, based on Palmer's mean value λ 4258.43 are:

For F type,	mean of 4	plates	= −3.6 km	
" F5G Pec.,	" " 3	"	= −5.7	Broad and fuzzy lines.
" K type,	" " 1	"	= +4.1	
" Mb "	" " 4	"	= +5.0	

These figures will no doubt be changed somewhat by more extensive measures.

The shifting of the center of the blend indicates an increase in intensity and probably also a widening of λ 4258.477 as we go from the F to the M types, which is in the same direction as from the Sun to the sun-spots.

λ 4283.169 *Ca* Intensity in Sun, 4 In sun-spots, 5

The preliminary residuals seem to indicate a widening toward the violet in the G types, and toward the red in K5M and Mb types, but this cannot be considered as established until confirmed by a longer series of observations.

Residuals (in km)

F	F8G	G	G5K	K	K2M	K5M	Mb
+1.2	−2.3	−3.1	−1.7	+0.5	+1.5	+3.4	+4.3
+0.9	−0.8	−1.7		+1.6	−1.7	+3.0	+1.2
+1.9	−0.3	−2.0		−1.8		+5.3	
−0.2		−3.2					
+3.1							
+3.3							

λ 4299.989 Intensity in Sun, 1N
4300.211 *Ti* 3 In sun-spots, 2–3

In the F type this line is very strong and sharp. It is much weaker in the G type, and still weaker in the Mb type. The F, G and K types give small positive residuals, while two plates of type K5M give small negative residuals. This shift, if confirmed by a longer series, would indicate in the M types a weakening of the *Ti* line sufficiently to make λ 4299.989 1N effective.

λ 4337.72 *Cr* Intensity in Sun, 3 In sun-spots, 4
38.08 *Ti* Intensity in Sun, 4 In sun-spots, 3
.43 *Fe* Intensity in Sun, 1 In sun-spots, 1–2

In the F type this line is sharp, strong, and of slightly greater than average width, and the residuals show it to have practically the wave-length of the *Ti* component. In the G type it is broad and fuzzy, and occasionally the *Cr* and *Fe* lines are separated by a darker region. In the M types the *Ti* line is very much weakened, in fact almost absent, making the *Cr* line look sharp and narrow.

λ 4339.617 *Cr* Intensity in Sun, 4 In sun-spots, 5
.822 *Cr* Intensity in Sun, 3

This blend is very faint in the F type. In the G type it is fairly strong. In the M type it is very strong and sharp, and the components show a decided tendency toward resolution. Both components seem to increase in intensity, and the blend gives good velocities for types from G to M, there being no shift either way, as is shown by the following residuals:

G	G5K	K	K2M and K5M	Mb
+1.8	±0.0	−2.5	+0.4	−0.5 km
	−1.2	+0.3	−1.4	+0.7
	+1.2	+0.9	−1.1	−0.1
			+2.1	+0.8

		Intensity in Sun	In Sun-spots	
λ 4340.634	*Hγ*	20N	15	weakened on red edge mainly.

This line is stronger in the F type than in the G type. In the M type it is very weak, probably less than one-tenth of its intensity in the F type. There is a tendency to give positive residuals in the F and G types, and negative residuals in the M types, the residuals in each case being small, however.

A5F	F	F8G Pec	F8G	G	G5K	K	K5M	Mb
+3.9	+1.8	+5.8	+2.4	+1.5	+1.2	−0.8	−1.0	−1.3km
	+0.8		−0.8	+2.7	+2.3	+1.1	−3.3	−0.4
	+1.9		+3.9	+1.6	+2.2	+1.3	−0.1 (K2*M*)	−1.3
	+3.9			+2.0	+0.8	+1.5	−2.9	
	+1.6			+1.9	+0.8	+0.1	−0.8	
	+2.2			+1.8		+1.4	−1.5	
	+1.5					−2.2		
						−2.0		
						+0.6		
						+1.2		
						−2.1		
						+2.9		
						+1.0		
						+0.5		
						+1.6		
						+1.4		
						−0.6		

		In Sun	In Sun-spots	In *Arcturus*	
λ 4352.908	*Fe*	4	6–7	7–8	widened toward red.
53.044	*V*	0			

In the F type this line is faint and narrow. In the G type it is more than twice as strong, and it continues to increase in strength

through the K to the M types, where it is more than four times as strong as in the F type. The consistent trend and small range of the residuals indicate that this line can safely be used, if allowance is made for the type. The residuals show that the widening toward the red becomes quite marked in the K type, and increases through the $K5M_4$ to the Mb type. There is little doubt that this blend will also give good results in the F type.

F8 G and F8 G Pec	G	G5 K	K	K2M and K5 M	Mb
−3.7	+0.8	−0.7	+1.6	+3.6	+3.4 km
+1.5	+1.0	−0.6	+3.1	+3.0	+4.9
−1.0	+1.7	+2.2	+0.8	+3.0	+4.6
+1.5	−1.1	+2.8	+1.4	+1.0	+4.7
−3.5		±0.0	+2.6	+3.9	+3.9
		+1.7	+3.1	+2.2	+6.5
			+1.5	+4.4	
			+2.2	+3.3	
			+0.8		
			+2.0		
			+0.9		
			+2.1		
			+3.4		
			+2.6		
			+1.4		
			+4.8		
			+2.2		
			−0.2		
			+0.8		
			+4.3		
			+1.9		
			+3.2		
			+3.6		
Means −1.0	+0.8		+2.2	+3.0	+4.7

λ 4355.257 *Ca?* Intensity in Sun, 2 In sun-spots, 2–3, In *Arcturus*, 3
.509 Intensity in Sun, 0

In the F type this line is vv faint. In the G and K types it is usually good, being stronger in the K type, however, than in the G type. In the M type it is broader and generally fuzzy.

λ 4371.14 *Zr* Intensity in Sun, 1 In sun-spots, n.c.
.22 Intensity in Sun, 1 In sun-spots, n.c.
.32 Intensity in Sun, 0 In sun-spots, n.c.
.44 *Cr* Intensity in Sun, 2 In sun-spots, 3–4
} In *Arcturus*, 6

This blend is frequently resolved into two components, the one toward the red being in all cases brighter than the one toward the

violet. They are faint in the F type, both components are stronger in the G type, and in going toward the M type the component toward the red alone seems to increase in strength. My residuals, which are principally for types K and K5M, give for the wave-length of this blend the value λ 4371.368, which is slightly greater than would be obtained from blending the component according to their intensities in the sun-spots (λ 4371.356).

λ 4387.007 *Ti?* Intensity in Sun, 1 In sun-spots, 0

This line is best in the F type, but it has a slightly fuzzy appearance. It diminishes in brightness in the G and K types, and in the M types it is nearly gone. The few residuals that I have are all plus, but small, which tends to show that the solar companion at λ 4387.220, 1N, has but a slight effect in determining the position of the center of the blend.

λ 4390.149 *V* Intensity in Sun, 2 In sun-spots, 3–4 In *Arcturus*, 3–4

This line is very faint in the F type and increases in strength continuously through the G and K types to the M type. For this

G	G5K	K	K5M	Mb
−0.8 (Sky)	−1.5	−2.7	+1.1	+1.8
−5.1	−2.9	−1.9	−0.9	+4.0
−3.7		−1.9	−0.5	+0.2 (Ma)
−3.4		−4.0	−3.2	+2.6
		−4.5	+0.4	+1.0
		−3.1	+1.0	±0.0
		−3.1	+0.4	−0.6
		+1.5	+0.2	+1.6
		−2.2	−0.7	+0.9
		−3.5	−0.3	
		−6.9	−0.1 (K2M)	
		−0.9	−0.4	
		+0.9	−2.0 (K2M)	
		−3.0		
		−1.9		
		−4.1		
		−2.1		
		−4.4		
		−2.8		
		−3.0		
		−0.7		
		−2.3		
Means −3.2		−2.7	−0.4	+1.3

line Dr. Palmer found the values λ 4390.118 for types F, G, and K, and 4390.178 for types K5M and M. My residuals, however, show

that the variation of the wave-length is progressive, the residuals changing from fairly large negative values in the G type to nearly zero values in the K5M type and positive residuals in the Mb type. The line is widened gradually toward the longer wave-lengths as we proceed from the G to the Mb types.

λ 4395.201 *Ti* Intensity in Sun, 3 In sun-spots, 3–4
.413 *V, Zr* 2 3 } In *Arcturus*, 7

This line increases continuously in width and intensity from the F to the Mb type. It is fairly sharp in all of these types, even in the Mb type where it is very broad and strong. Both components increase in intensity, but the residuals show a gradual and continuous shift of the center of the blend toward the red. It is an easy line to set on with the micrometer thread, and the residuals indicate that it gives excellent results.

F	F8G	G	G5K	K	K5M	Mb
−3.9	−2.2	−0.8	+0.1	±0.0	+1.7	+2.4 km
−2.7	−4.1	+0.2	−1.8	−0.5	+0.9	+2.7
−0.5			+0.3	+0.8		+2.9
−1.8				−0.3		
				+0.1		
				−1.2		
				+0.3		
				+0.1		
				+0.3		
				+0.6		
Means −2.2	−3.2	−0.4		±0.0	+1.3	+2.7

λ 4400.555 *Sc* Intensity in Sun, 3
.738 *V* 1 In sun-spots, 2–3 In *Arcturus*, 3

My value for the wave-length of the blend as obtained for types K and K2M is somewhat greater than the value obtained by blending the components with the intensities 3 and 3. The residuals show the gradual shifting of the center of the blend toward the red as we go from the F to the Mb type. In the F type the line is narrow and very good, the vanadium component being absent. In the G type the vanadium component becomes effective. In the Mb type it has the same intensity as the *Sc* component, and the resulting blend is strong and broad.

λ 4406.810 *V* Intensity in Sun, 2 In sun-spots, 4 In *Arcturus*, 5

This line is good in types G to Mb, and increases in strength in

the same direction. In the F and F8G types it is scarcely visible. The preliminary residuals indicate no shift of its center.

λ 4407.810 *V* Intensity in Sun, 2
.871 *Fe* 4
In sun-spots, 7–8, In *Arcturus*, 7

This line is good in types F to Mb, and it is not much wider in the latter than in the former. The residuals seem to indicate a slight shift toward the violet, but this is still uncertain. A large shift cannot be expected from such close components, and it will require a longer series of measures to show which component is increased in intensity, if they are not both increased.

λ 4408.364	*V*	Intensity in Sun, 2	In sun-spots, 3	In *Arcturus*, 3
.582	*Fe*	3	6	6
.683	*V*	2		

This line is good in types F to Mb. It increases considerably in intensity and in width, and occasionally it is somewhat fuzzy in the Mb type. The residuals indicate that it widens symmetrically.

λ 4416.636	*V*	Intensity in Sun, 0	In sun-spots, 2–3	In *Arcturus*, 3
.985		2	1–2	1

In the F types the vanadium component is absent or at least not effective, and the line λ 4416.985 is very good. In the types G and K the vanadium companion begins to appear, and the blend is usually fuzzy. In the M types the vanadium component is strong, considerably stronger than the other component, which is also shown by the large negative residuals in these types. The value of the wave-length for the Mb type (λ 4416.746) as obtained from the residuals is in fair agreement with the value of the blend according to intensities in the sun-spots (λ 4416.723).

F	F8G	K	Mb
+1.1	+1.8	+1.3	−16.5
+0.5			−15.9
−1.0			−15.9
+1.8			−16.6
			−16.8
			−16.1

λ 4417.450 *Ti* Intensity in Sun, 0
.577 *Co* ∞
In sun-spots, 2 In *Arcturus*, 3
.740 ∞
.844 *Ti* 3

In the F type the line is narrow and good, the *Ti* component λ 4417.844 alone being effective, as is shown by the residuals. In the G type the line is still fair, but in the K and M types the companions at λλ 4417.450 and .577 have become of about the same intensity as the line .844. In the K and M types the line is usually very fuzzy, and on good plates the two components are resolved.

λ 4425.608 *Ca* Intensity in Sun, 4
26.201 *Ti* o Nd? In sun-spots, 2 In *Arcturus* 2

The *Ti* component is absent in the F type. In the G type it shows but is quite faint. In the K type it is as strong as the *Ca* line, while in the Mb type it is about twice as strong as the *Ca* line, i. e., intensity 8. The two lines are usually completely resolved, but occasionally they are somewhat run together.

λ 4427.266 *Ti* Intensity in Sun, 2 In sun-spots, 3
.482 *Fe* 5 n.c. } In *Arcturus*, 8

This line broadens somewhat from the F to the Mb types, and increases considerably in strength. It is usually very good in types F8G to Mb, and the residuals show that it gives excellent results. A larger number of residuals will be required to establish definitely the apparent slight shift of the center of the blend toward the violet in the Mb type.

λ 4428.711 *V–Cr* Intensity in Sun, 1 d? In sun-spots 2 In *Arcturus*, 2

In the F type this line is absent. In the G type it is very faint but usually measurable . It increases in strength from the K to the M types and is a very good line. It is apparently shifted toward the violet in the M types, and this is also borne out by the trend of the few residuals that I have, and by my value of the wave-length (λ 4428.684) which was found for types K to M. If it is double, as indicated by Rowland, it is probably the component toward the violet that is intensified.

G 5 K	K	K 2 M	K 5 M	Mb
+3.6	+2.5	−0.8	−3.3	−2.5 km −2.6

λ 4433.948 *Fe* Intensity in Sun, 1 In sun-spots, n.c.
34.168 *Ti* o Nd? 1 } In *Arcturus*, 2

This line is very faint and fuzzy in the F type. In the types G to Mb it is fair. The wave-length found for it from the plates for types G5K to Mb is λ 4434.066, which is in good agreement with the value λ 4434.058 obtained by blending the components with the intensities given for them in the sun-spots.

λ 4435.129 *Ca* Intensity in Sun, 5 In sun-spots, 6
.321 *Fe* 2 n.c. } In *Arcturus*, 8

This line is good, especially in types F and G. It increases in strength continuously from the F to the Mb types. My value of the wave-length, 4435.201, is in good agreement with the value 4435.208 that would be obtained by blending with intensities 5 and 3 respectively. This value and the trend of the residuals indicate a shifting of the center of the blend toward the red as we go from the F to the Mb type. This is in the opposite direction from that indicated by the intensities of the components as given by Adams for the sun-spot spectra.

F	F8G	G	G5K	K	K5M	Mb
−3.4	−0.2 −3.2	−1.0 −2.5	+0.8	+1.9 −0.4 −1.4 +0.2 −0.6 +0.6 +1.1	+1.8 (K2M) +3.3	+1.3 km +3.7 +1.0 +1.2

λ 4441.881 *V* Intensity in Sun, 3 Nd? In sun-spots, 5 In *Arcturus*, 4–5

This line is good in types F to Mb, increasing in strength in the same direction. The residuals do not show any decided evidence of shift from type to type.

λ 4443.976 *Ti* Intensity in Sun, 5 In sun-spots, 4–5 In *Arcturus*, 4–5

This line is strong and sharp in the F type, being several times as strong as in the G type. It continues to diminish in intensity from the G to the Mb type, where it is quite faint and fuzzy. It is not good for measurement in the Mb type with the dispersion of the southern Mills spectrograph.

λ 4468.663 *Ti* Intensity in Sun, 5 In sun-spots, 4–5 In *Arcturus*, n.c.

This is a good line in all types from F to Mb. It is quite strong in the F type. It seems to broaden somewhat toward the red in the

M type. The progressive trend of the residuals from negative values in the F type to approximately zero values in the G5K type and large positive residuals in the Mb type is very decided.

F	F8G	G	G5K	K	K5M	Mb
−1.3	−2.2	−0.3	+1.4	+2.8	+5.7	+6.8 km
+1.7	−0.3	−1.5	+0.9	+2.6	+0.8	+7.0
−4.1	−2.9	−0.9	−0.7	+3.9	+6.3	+3.5
−3.0	−0.9		−0.9	+1.1	+2.5	+6.1
−3.7	+1.4		+2.7	+1.0	+4.7	+4.8
			−2.1	+0.6	+4.7	+1.9
				+2.2	+4.7	+1.7
				+0.4	+5.2	+5.9
				−0.4		
				+1.2		
				+1.3		
				+2.7		
				+3.7		
				+4.3		
				+1.5		
				−0.3		
				+1.9		
				+0.6		
				+0.4		
				−1.5		
				−3.0		
				+3.3		
				−0.1		
				+0.7		
Means −2.1	−1.0	−0.9	+0.2	+1.3	+4.3	+4.7

MOUNT HAMILTON,
October 19, 1906.

ORBIT OF THE SPECTROSCOPIC BINARY λ *ANDROMEDAE*

By KEIVIN BURNS

λ *Andromedae* (1900, $a = 23^h\ 32^m.6$, $\delta = +45°\ 56'$) is a K-type star of photographic magnitude 5.0. The lines are very sharp, especially in the region of $H\gamma$. The binary character of this star was announced by Campbell[1] in 1899, and plates taken later in the same year showed the period to be $20^d.5$. The first eighteen plates were taken with the original Mills spectrograph,[2] $H\gamma$ central, and the others with the remounted Mills spectrograph (λ 4500 central; collimator, $f = 724$ mm (28.5 inches); camera $f = 521$ mm (20.5 inches); titanium comparisons). The star is relatively fainter in the region of λ 4500, $1^h\ 30^m$ exposure being required to give the same density as was obtained in $1^h\ 05^m$ with $H\gamma$ central. However, a part of the increase is due to the greater focal length of the second camera. Definitive measurements seemed to show a discrepancy between the series taken with the first Mills spectrograph and the plates taken with the second Mills, and a complete series was secured with the new instrument in order to determine the nature of the disagreement. Following is a list of the plates of this star, and of check-plates measured in connection with the two series.

No.	Plate	Gr. M. T.			Velocity
1	546 B	1897	November	16.712	+11.05 km
2	1015 B	1898	October	18.719	1.04
3	1041 D		October	26.828	8.50
4	1322 D	1899	July	5.935	12.28
5	1327 A		July	11.956	2.19
6	1331 D		July	12.929	1.65
7	1338 D		July	16.948	1.47
8	1349 D		July	24.995	13.02
9	1369 C		August	2.897	0.38
10	1378 D		August	8.976	4.67
11	1459 C		September	11.778	2.41
12	1486 B		September	21.744	12.12
13	1511 C		October	16.776	12.03
14	1518 B		October	17.769	9.68
15	1529 A		October	24.705	0.51
16	1539 A		November	1.680	10.53
17	1546 B		November	6.734	9.30

[1] *Astrophysical Journal*, 10, 178, 1899. [2] *Ibid.*, 8, 123, 1898.

No.	Plate	Gr. M. T.			Velocity
18	2544 A	1902	September	14.946	12.26
19	3366 F	1904	July	26.928	12.88
20	3398 B		August	16.791	13.70
21	3407 E		August	21.970	4.67
22	3425 A		September	4.786	13.02
23	3455 A		September	18.975	5.66
24	3458 B		September	19.906	8.78
25	3502 C		October	24.829	0.91
26	3527 A		November	7.633	11.15
27	3564 D		November	22.735	12.83
28	3693 A	1905	February	27.640	0.48
29	3820 A		June	7.985	2.29
30	3833 E		June	13.910	7.91
31	3837 E		June	14.928	10.61
32	3841 E		June	18.949	15.84
33	3844 D		June	19.935	14.40
34	3848 D		June	20.933	12.09
35	3853 E		June	21.963	8.97
36	3855 D		June	25.974	3.09
37	3858 D		June	27.981	1.10
38	3862 A		June	28.939	0.34
39	3865 D		July	1.985	2.84
40	3868 D		July	2.922	4.24
41	3895 B		July	7.949	13.37
42	3900 B		July	13.979	7.33
43	3914 B		July	19.918	1.34
44	3923 B		July	26.920	11.93
45	3928 B		August	1.910	10.06
46	3931 F		August	3.008	8.26
47	3935 A		August	3.993	7.36
48	3938 F		August	7.012	3.42
49	3948 D		August	14.007	6.83
50	3950 E		August	14.935	9.80
51	3980 E		September	3.912	8.58
52	3991 B		September	7.917	15.37
53	4001 A		September	14.879	5.44
54	4094 A		October	27.801	3.52
55	4321 D	1906	July	18.953	5.71
56	4345 E		July	30.883	+10.47

Venus

Plate	Date		Obs. Vel.	Comp. Vel.
1723A	1900	May 7	−13.37 km	−13.28 km
1995D		December 24	+ 8.23	+ 8.79
1996B		December 24	+ 8.7	+ 8.79
2288A	1901	October 21	−12.52	−12.13
2289B		October 21	−11.52	−12.13
[1]3573A	1904	November 28	−10.48	−10.45
[1]3574B		November 28	−10.52	−10.45
[1]3750A	1905	March 8	−12.77	−12.75
[1]3871E		July 2	+13.67	+13.47
			+13.59	
[1]3906E		July 17	+13.15	+13.30

[1] Second Mills Spectrograph.

Mars

Plate	Date	Obs. Vel.	Comp. Vel.
867D	1898 August 8	− 7.12	− 7.17
1006A	October 11	−10.29	−10.48
1976C	1900 December 4	−13.40	−13.84

An uncompleted investigation shows that an underexposed plate of a star as measured by the writer gives a positive residual, and Plates 21, 27, 47, being underexposed, were omitted from the discussion. Plate 29 was omitted on account of an irregular temperature-change.

Using Plates 2–17, inclusive, the following preliminary elements were obtained by the method of Lehmann-Filhés:

$$U = 20^{d}.5464$$
$$\mu = 17^{\circ}.5213$$
$$T = \text{J. D. } 2414572.12$$
$$\omega = 348^{\circ}.07$$
$$K = 6.85 \text{ km}$$
$$e = 0.099$$
$$V = +6.50 \text{ km}$$

In the equations of condition

$$x = \quad \delta V$$
$$y = \quad \delta K$$
$$z = [2469.]\ \delta\mu$$
$$u = [7.036]\ \delta e$$
$$v = [2.543]\ \delta T$$
$$w = [6.902]\ \delta\omega$$
$$n = [0.5]\ n.$$

The resulting normal equations are:

[aa]	[ab]	[ac]	[ad]	[ae]	[af]	[an]
+16.000x	+0.093y	+1.728z	+1.109u	+1.343v	+1.131w	+1.330=0
	+8.968	+0.548	−3.942	−0.337	−0.323	+2.344
		+6.044	−0.042	+5.011	+5.806	−0.519
			+6.356	+1.024	+1.425	−2.002
				+5.072	+5.673	−0.957
					+6.748	−1.366

The values of the unknowns are:

$$\delta V = -0.165 \qquad \delta e = +0.0333$$
$$\delta K = -0.368 \qquad \delta T = -0.313$$
$$\delta\mu = +0.00743 \qquad \delta\omega = -11^{\circ}.86.$$

The preliminary elements found by using Plates 19–54 (new Mills) are:

$U = 20^d.541$ $\quad K = 7.58$ km
$\mu = 17^\circ.5259$ $\quad e = 0.13$
$T =$ J. D. 2416682.97 $\quad V = +7.42$ km
$\omega = 293^\circ.42$

In the equations of condition:

$x = \delta V$ $\quad v = [2.989]\ \delta T$
$y = \delta K$ $\quad w = [8.470]\ \delta\omega$
$z = [4006]\ \delta\mu$ $\quad n = [0.1]\ n.$
$u = [7.901]\ \delta e$

The resulting normal equations are:

[aa]	[ab]	[ac]	[ad]	[ae]	[af]	[an]
$+32.000x$	$+2.196y$	$-1.416z$	$-3.971u$	$-0.603v$	$+0.004w$	$+0.513=0$
	$+13.379$	-1.255	-5.039	$+0.651$	$+0.842$	$+0.580$
		$+8.175$	$+0.109$	$+8.901$	$+9.834$	-0.525
			$+14.933$	-0.351	-0.753	$+0.170$
				$+12.511$	$+13.587$	-0.557
					$+15.012$	-0.579

from which

$\delta V = -0.126$ $\quad \delta e = -0.0438$
$\delta K = -0.511$ $\quad \delta T = +0.486$
$\delta\mu = +0.00459$ $\quad \delta\omega = -7.62.$

FINAL ELEMENTS

	OLD SERIES (1899)		NEW SERIES (1905)	
U	$20^d.538$		$20^d.546$	
μ	$17^\circ.529$	± 0.014	$17^\circ.521$	± 0.006
T	J. D. 2414571.81	± 0.37	2416683.46	± 0.39
ω	$336^\circ.2$	± 7.6	301.0	± 7.6
K	6.48 km	± 0.19	7.07	± 0.16
e	0.132	± 0.038	0.086	± 0.018
V	$+6.34$ km	± 0.13	7.43 km	± 0.10
$a \sin i$	1,810,000 km		1,990,000 km	
Probable error of single obsn.,		± 0.50 km		± 0.51 km

The change in elements, if real, may account for the rather large probable error of a single plate. The excellent lines in this star would lead one to expect somewhat better results. The large probable errors of the elements are due in a measure to the small range in velocity of the star.

By applying a constant correction to one series and changing the period to $20^{d}.523$ the observations can be satisfied, after a fashion, but there is no apparent reason why either step should be taken. At best the probable error is materially increased and the first observation is not represented. A series of plates taken after the lapse of a few years would no doubt establish or disprove the reality of the change

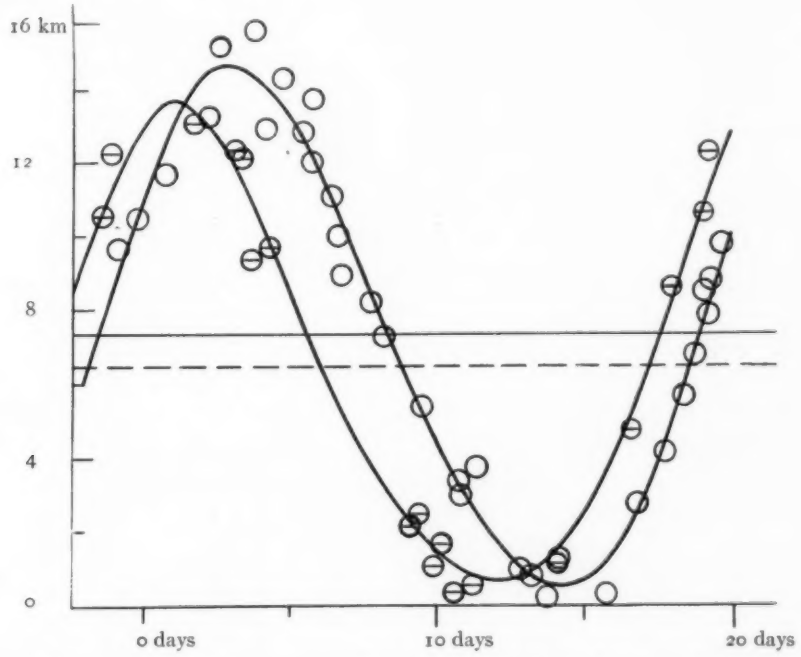

FIG. 1.—Barred circles represent observations of the first series; open circles those of the second series. The dotted line is the velocity of the center of mass for the old series; the continuous line that for the new series.

in elements. Such a series should be taken in a single cycle of $20^{d}.5$ if possible, in order to eliminate the effects of changing elements and error in period.

The discrepancy of the two sets of elements, if established, will no doubt be found to be due to a third body It is quite likely the line of apsides will be found to rotate, as the difference between ω in the two sets is some five times the probable error. The variation in V is

probably real, as the check-plates show no decided difference between plates taken with the first and second Mills spectrograph.

In the figure the *diameter* of the small circles represents the probable error of a single plate. The epochs for the velocity-curves are those given under the heading "final elements."

LICK OBSERVATORY,
Mount Hamilton, October 10, 1906.

THE TEMPERATURE OF THE MOON

By FRANK W. VERY

In a paper with the above title presented at the Ithaca meeting of the Physical Society, June 29 to July 3, 1906, of which an abstract appears in the *Physical Review*,[1] Mr. W. W. Coblentz announces the discovery that various common minerals which reflect only diffusively in the region of the spectrum of shorter wave-length than 8 μ have "bands of metallic reflection from 8.5 to 10 μ," and he draws the conclusion that "the Earth and the Moon may be considered selectively reflecting surfaces with a band of metallic reflection from 8.5 to 10 μ."

Admitting the value of this part of his conclusion, the next step of the argument does not necessarily follow. "The radiation from the Sun," he asserts, "is so much more intense than that of the Moon that, with a reflecting power of 50 to 90 per cent., at 8 to 10 μ one would expect the amount of reflected energy to be, at all times, greater than the direct radiation from the Moon." On the assumption that the extreme infra-red maximum in the energy-curve of the lunar spectrum is due to metallic reflection, Dr. Coblentz arrives at the result that "Langley's first conclusion of a lunar temperature of—225° C. again obtains."

This extension of E. F. Nichols' discovery[2] that quartz has bands of metallic reflection beyond 8 μ by which Dr. Coblentz proves that the property is shared by various common silicates, is of interest as a physical fact, but it cannot be accepted as proving "the radiation from the Moon at 8.5 μ to 10 μ to be reflected from the Sun," nor as indicating that the temperature of the sunlit Moon is about 225° C. below zero, for the following reasons:

1. If the Moon reflected specularly, there should be a maximum of heat in the lunar image at first quarter at a point seven-tenths of the distance from the center of the lunar disk to the west limb. Instead of this, the maximum heat is at the west limb, where it should

[1] **23**, 247, September 1906.

[2] *Physical Review*, **4**, 297, 1897.

be if the Moon radiates as a hot body, heated by the Sun's rays. Indeed, a comparison of the isothermals of the lunar surface in Figs. 11 and 12 of my *Prize Essay on the Distribution of the Moon's Heat and its Variation with the Phase*,[1] where the Moon's age is respectively 7.7 and 10.6 days, suggests that possibly the maximum point may be a little on the farther side of the Moon at first quarter.

2. The spectral energy-curve of the Moon's radiation is not a band from 8.5 to 10 μ but a continuous spectrum. After elimination of a portion of shorter wave-length than 3 μ which agrees in form with the corresponding solar curve, and is obviously reflected, the lunar curve exhibits a similarity in its limits, and when corrected for the absorption by the Earth's atmosphere, it also shows a similarity in its form with the spectral energy-curve of a heated body.

It is true, the observed lunar curve has its maximum in the region of the bands discovered by Nichols and Coblentz, but this curve is obtained after the radiation has suffered an enormous absorption by atmospheric water-vapor in the region of the great water bands between 5 and 8 μ. These bands transform an original maximum in the lunar spectrum, if it could be observed outside our atmosphere, into a minimum. When corrections for atmospheric absorption are applied, the restored curve is found to be that appertaining to bodies not much below the temperature of boiling water; and as the measurements which have been made in the spectrum are integrations including the radiations from extensive areas on which the Sun is shining at a low angle, and which are much below the maximum temperature, the latter may easily exceed 100° C., as I have shown it probably does in my paper on "The Probable Range of Temperature on the Moon."[2]

These statements may be proved in another way, by measuring the radiation at selected points in the lunar spectrum beyond 10 μ, where the atmospheric absorption does not interfere very much. At such points in the lunar spectrum, although the energy is small and not easy to measure, there is substantial agreement with the radiation of screens containing hot water.

3. The Moon reflects diffusely about one-eighth of the solar rays

[1] Published by the Utrecht Society of Arts and Sciences, The Hague, 1891.

[2] *Astrophysical Journal*, **8**, 199 and 265, 1898.

between 0.3 and 3.0 μ, giving a spectral energy-curve of reflected radiation about half as high as the observed extreme infra-red maximum. But at 8.5 to 10 μ, the energy in the solar spectrum is hardly one-hundredth part as great as at 1 μ. Theory as developed by Wien, Paschen, and others, gives a ratio much smaller than even this, a point on which I have commented in my paper on "The Solar Constant."[1] Taking the measured ratio of intensities, however, a lunar maximum at about 9 μ, if due to solar rays of that wave-length specularly reflected, should bear a ratio to the diffusely reflected maximum of shorter wave-length, determined by this ratio of original intensities in the given regions of the solar spectrum, by the ratio of reflecting powers which may approach 1:8,[2] and by the ratio of the solid angle filled by the Sun to the hemisphere, or approximately

$$(\tfrac{1}{100}\times 8\times 100{,}000):1 = 8{,}000:1.$$

Owing to the roughness of the Moon's surface, it cannot reflect like a polished spherical mirror, and an unknown correction for the spreading of the specularly reflected rays remains to be applied; still, there is, no doubt, abundant radiant energy to affect an instrument of small aperture if sufficiently sensitive. A search for this small solar image in rays of 8.5 to 10 μ wave-lengths should be made at the proper point in the lunar image at a distance from the center of the disk,

$$V = \cos \tfrac{1}{2} \text{ Moon's elongation},$$

with a delicate heat-measuring instrument, covered by a screen with a pin-hole aperture. There is a strong probability that it will be found, whenever the experiment is made under the right conditions. But this solar image at a circumscribed point in the lunar image formed by a concave mirror, is not the source of the spectrum observed at all parts of the lunar disk. This spectrum must be due to rays emitted from a heated body.

4. It is not true that the drop in lunar radiation during a lunar eclipse "from a maximum to a minimum in about 1.5 hours . . . . would seem to indicate that the observed radiation is reflected from

[1] *Monthly Weather Review*, August 1901; reprinted as Weather Bureau Publication, No. 254 (see p. 23).

[2] I note that Mr. Coblentz speaks of the reflection of short waves as "practically zero," but this is an exaggeration.

the Sun, since the lapse of time is so short." For, let a mass of rock of considerable size, having a boring in which a thermometer is inserted, be heated in an oven until a nearly uniform temperature of between 100 and 200° C. is attained throughout its mass, and let it then be transferred to a receiver (preferably vacuous, to more nearly resemble lunar conditions) surrounded by a freezing mixture. I have never made the experiment in exactly that form, but have approached near enough to it to know that in an hour and a half a surface pellicle of rock will have cooled until it radiates only feebly, while, nevertheless, the interior of the mass is still hot. Under these circumstances, if the body is put back into the oven, its surface temperature will be restored quickly, because only a thin layer has to be reheated.

Now, this is just what happens on the Moon during an eclipse. It has taken two weeks of sunshine to produce the high temperature of the full Moon; but after the eclipse is over, the radiation is not much smaller than before. A few hours of sunshine replenish the thin layer cooled during the eclipse.

I have made several measurements of the heat derived from the image of the eclipsed Moon. In one of these "the umbra of the eclipsed Moon was found sufficiently hot to appreciably affect a bolometer covering as little as one thirty-fourth of the Moon's disk, by an amount equal to about 1 per cent. of the heat which was to be expected from the full Moon, the radiations being of a quality to which glass was impermeable."[1] Other observations showed a progressive diminution of this small remnant during totality.

In my "Photometry of a Lunar Eclipse"[2] it is shown that the light of the eclipsed Moon may be as small as

0.0000000042

of that from the full Moon. These facts prove that there is no resemblance between the behavior during an eclipse of the infra-red rays from the Moon of longer wave-length than 4 μ, and of those rays which are undoubtedly reflected from the Sun.

WESTWOOD, MASS.,
October 1906

[1] *Prize Essay on the Distribution of the Moon's Heat*, p. 40.

[2] *Astrophysical Journal*, **2**, 293, 1895.

ON THE CONNECTION BETWEEN DISTURBED AREAS OF THE SOLAR SURFACE AND THE SOLAR CORONA

By A. L. CORTIE

That there exists a general connection between the state of disturbance of the Sun's surface and immediate surroundings, and the solar corona, is well established. There is a great similarity in type in the photographs of the solar corona of the years 1870, 1882, 1893, and 1905, all of them years of maximum solar activity, marked by many and great outbursts of sun-spots and prominences. A quite different type of corona corresponds to the years of minimum solar activity, as witness the photographs of 1878, 1889, and 1901; while yet again a type of corona intermediate between those of years of maximum and minimum solar activity is associated with the years of waning sun-spots and prominences, 1886 and 1896. But it is open to question whether the sun-spots or the prominences are the more intimately connected with the streamers which constitute the characteristic forms of these variations in coronal type. In the Stonyhurst photographs of the solar corona of 1905 August 30, taken at Vinaroz, Spain, the streamers seem in general to mark the regions of the prominences rather than of the sun-spots. The longest streamers photographed, consisting of two long wings with an intermediate shorter streamer, extend from latitude $-40°$ to $-90°$ S., outside the limits of the spot zones, while another streamer is placed near the Sun's north pole. Moreover, the general tendency of all the more marked streamers is poleward, while the fine group of prominences in the northeast quadrant is manifestly associated with three fine streamers. In the lower corona the complicated structures of arches and vortex rings are attached to the prominences. In this connection it will be interesting to quote from Mr. Evershed's account of the prominences of 1905:[1] "The polar regions of the Sun have again been nearly quiescent, although the high latitude zones of activity have made a distinct advance toward the poles. These prominences were found to be most frequent between the parallels 65° and 70° in both hemispheres, and the limits of promi-

nence-formation at the close of the year may be put at $+75°$ and $-75°$."[1] It would seem that the poleward tendency noticed in the streamers of the corona, in the main, was also characteristic of the prominences observed during the year, which again were most frequent in latitudes greater than those of the spot-zones.

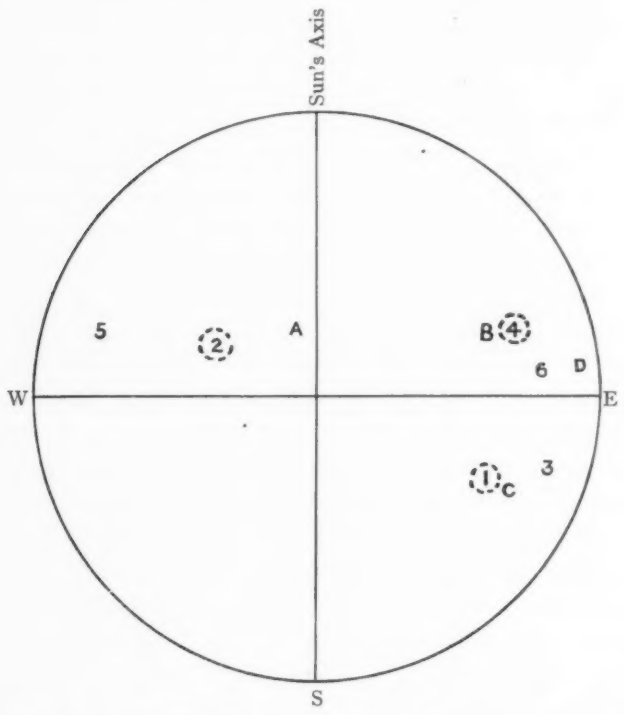

FIG. 1.—Positions of centers of sun-spot activity 1905, August 30. A, B, C, D, are positions of spots visible on the day of eclipse. The 1 within a dotted circle is the sun-spot center, January 5–July 14.

In the photographs of the corona of 1905 August 30, the sun-spot zones are marked by some straight radial bright rays in the southwest quadrant, and by some beautiful plumes in the southeast quadrant.[2] These rays and plumes are well shown in the third

[1] *Monthly Notices*, **66**, 227, February 1906.

[2] See Capt. Carpenter's drawing from the photographs taken by the party from the U. S. Naval Observatory. *Astrophysical Journal*, **23**, Plate IX, opposite p. 13c. 1906.

plate of the Stonyhurst series, exposed for 15 seconds near the beginning of totality on a Schleussner's "Observatory" plate. The instrument employed was the full aperture of the 4-inch lens of the 20-foot coronagraph belonging to the Royal Irish Academy. In the discussion of the results of the eclipse, presented to the Royal Irish Academy, it was shown that the area on the solar surface to which the projected images of these plumes converged was situated in the southeast quadrant, the mean latitude of the position being approximately $-21°$ S. Four sun-spot groups were visible on the Sun's surface on the day of the eclipse, and the largest of the four, marked C. on the diagram, with an area of one-thousandth of the Sun's visible disk, had a mean latitude $-20°$ S., and was removed about 41° from the Sun's east limb. Moreover, of the two limbs, the east limb on the day of eclipse had the greater number of sun-spot centers of greater activity during the year in its vicinity, including among them, though on the invisible hemisphere of the Sun and removed some 51° from the limb in latitude $-16°$, that center which had been the seat of the outburst of the great sun-spot group of February 1905, the greatest observed for thirty years. If the plumes converged to an area behind the visible disk, then it was possible that they were connected with the great February spot; if to an area on the visible hemisphere, the possibility was that they were attached to the spot seen on the day of the eclipse, especially as it was near the place of a large group, marked 3 on the diagram, visible to the naked eye during the preceding July. Since writing the memoir for the *Transactions* of the Royal Irish Academy, the life-histories of the spots and faculae that occupied these two regions of disturbance have been carefully studied from the Stonyhurst sun-spot drawings. The results of this study are set forth in the following tables, and the discussion which accompanies them. The measures, unless otherwise stated, have been made on the Stonyhurst drawings.

After this date the region becomes quiescent and remains so during the period of the eclipse. In the next table the region of a great spot visible during July is similarly treated, the spot marked 3 on the diagram.

TABLE I

1905 Region of Disturbance on the Sun Connected with the Great February Spot

Appearance	Date, 1905	Mean Longitude	Mean Latitude	Remarks
I	January 5.42	319°.52	−18°.60	A small spot, built of great spot.
	January 11.44	322.63	−18.39	A group of small spots.
II	January 31.40	329.30	−17.50	A very large spot.
III	March 2.46	319.34	−18.75	A fairly large spot.
IV	March 27.66	324.35	−16.30	The spot very much smaller.
	April 6.33	320.71	−20.50	April 5 a single dot; April 6 positions
		318.71	−26.50	of two dots in bright faculae near W. limb.
V	May 3.48	325.75	−22.96	Faculae near W. limb.
VI	May 29.66	320.88	−26.49	Very faint faculous patch near W. limb.
VII	June 15.29	331.19	−22.20	Small spot in faculae near the position of the great spot, died on June 21.
	June 25.34	327.66	−25.84	Bright faculae in region of small spot.
VIII	July 14.32	320.51	−29.74	Bright faculae E, about same region as that of June 25.

TABLE II

1905. Region of Disturbance on the Sun Connected With a Great July Spot

Appearance	Date, 1905	Mean Longitude	Mean Latitude	Remarks
I	May 17.34	68°.31	−15°.23	Leading spot of an extended large group.
		53.81	−16.23	Following spot of the same group.
II	June 15.29	70.25	−16.80	Leading spot of the group.
		53.25	−16.21	Following spot of the group.
III	July 14.32	52.52	−15.65	Center of fine group of scattered spots visible to the naked eye. Position of following spot of former group.
IV	August 6.55	61.24	−16.78	Center of a large spot.
V	August 30.33	60.20	−18.70	Biggest spot on day of eclipse. Greenwich measure.

In studying this group, a set of measures, kindly supplied to me by Mr. Maunder, of Greenwich, has been of great assistance for purposes of identification. This region was disturbed, according to the Stonyhurst drawings, from May 11 and was active on August 30, the day of the eclipse, and afterward. Therefore it follows that the connection, if any, between the coronal plumes and a disturbed area on the Sun must be postulated of this second area. Is the connection merely one of coincidence of position, and not a real con-

vergence of the plumes to the spot area? The probability of the reality of the connection seems greatly enhanced by the study of a similar region in 1893, which was the area of convergence of a like system of rays or plumes in the lower corona of April 16. The material used in this last table has been taken from the Greenwich volume of *Photographic Results* of that year. The comparison is made with Professor Schaeberle's discussion of the eclipse photographs in the "Report of the Total Solar Eclipse of April 16, 1893" (*Contributions from the Lick Observatory*, No. 4).

TABLE III

1893. INTERMITTENTLY DISTURBED REGION OF THE SUN, MARCH 15–NOVEMBER 16

Appearance	Date, 1893	Greenwich Number	Mean Longitude	Mean Latitude
I	March 15–21	2881	42°.10	−8°.16
II	April 5–18	2914	44.56	−8.46
III	May 3–10	2959	45.86	−7.54
IV	Sept. 17–27	3187	49.30	−8.08
V	Nov. 12–16	3275	47.02	−8.26

This area, which was continuously active from a month before the eclipse to nearly a month afterward, and again broke out into disturbance in September and November, was placed on the eclipse day about 34° from the Sun's west limb with position angle 237°. In Professor Schaeberle's Skeleton Diagram of Corona, Plate IX, facing p. 89 (*loc. cit.*), is an object marked π, of which we read (p. 100, *loc. cit.*): "The heaviest of a number of much inclined and conspicuous streamers issuing between P. A. 230° and P. A. 250° of the Sun's outline . . . . on account of the numerous crossing of streamers from greater position angles the individual directions cannot be ascertained with certainty. At about P. A. 210° the bunching up from intensities is so great that from height $=10'$ to height $=15'$ an apparent increase of density in the corona takes place." In his discussion of results Professor Schaeberle distinguishes coronal arches and coronal streamers; but, so far as can be made out from a comparative study of the eclipse photographs of Professor Schaeberle and those of the English observers, Mr. Kearney and Mr. Taylor, the structure described in the above quotation is very like that named as plumes on the Stonyhurst plates of 1905.

Without subscribing entirely to the mechanical theory of the solar corona as advocated by Professor Schaeberle, and above all to the statement (p. 126, *loc. cit.*) that "there is no evidence to indicate that either electricity or magnetism has anything to do with the arrangement of coronal matter in the Sun's neighborhood;" and, moreover. admitting the sorting effect on the lighter materials ejected from the Sun due to the pressure of light, yet, in any discussion of the constitution of the corona, the great part played by the ejective forces in the Sun, actively displayed in sun-spots and prominences, must be fully admitted, and any theory which rejects or overlooks the effect of such forces must be regarded as incomplete. The present paper gives highly probable evidence that not only in general is a characteristic type of solar corona associated with sun-spot and prominence activity, but that definite structures in the corona are associated with definite areas of activity of sun-spots and faculae.

STONYHURST OBSERVATORY,
July 27, 1906.

Minor Contributions and Notes

VARIABLE RADIAL VELOCITY OF δ *CAPRICORNI*

The following observations of the velocity in the line of sight of δ *Capricorni* show it to be a spectroscopic binary of rather short period.

1906, September 25, Radial Velocity, —30 km
October 3, " " —79

The spectrum of this star belongs to Miss Maury's class *Xa,b*. The lines, although numerous, are rather broad and not suited to accurate measurement.

V. M. Slipher.

Lowell Observatory,
October 5, 1906.

Reviews

Stark's Theory of Radiation.

During the present year considerable work on the radiation of light by canal rays has been done by J. Stark and his co-workers[1] at Göttingen. Their experimental results are interesting, and some of the conclusions which Stark draws from them, if justified, are of very great importance.

It has been known for some time that canal rays consist of positively charged particles, whose mass is of the order of magnitude of that of the atom of the gas in which they are produced; that they move with a high velocity (10^7 cm sec., or more); and that light is emitted by that part of the tube through which they move. If this light, wholly or in part, comes from the moving particles, it should exhibit the "Doppler effect" when viewed in a direction parallel to the motion. Stark has observed the spectrum of the canal rays in hydrogen, nitrogen, potassium, and mercury, and finds the effect only in case of line-spectra, the band-spectra showing none whatever. This indicates that line-spectra owe their origin to the positive ion. He finds also that all the lines belonging to the same series exhibit the same Doppler effect, while different series may show the effect in different amounts. In mercury, for example, the series of triplets give roughly twice the displacement shown by certain other lines which he arranges in a series of doublets; while the line λ 4078.1 gives a displacement greater than that of the triplets. Assuming the mass of the moving particle as that of a mercury atom, knowing the cathode fall of potential in the tube, and measuring the Doppler effect, he finds that the series of triplets is emitted by atoms which have lost two electrons; his series of doublets, by atoms which have lost only one; while the line λ 4078.1 is emitted by atoms which have lost more than two electrons. The hydrogen series and the principal series of potassium, both of which consist of doublets, are similarly shown to be due to atoms which have lost one electron.

Stark assumes that band-spectra owe their origin to the system composed of the positive ion and one or more electrons when in the act of recombining to form a neutral atom, and he supports this idea by some very ingenious experiments with a mercury tube.

Another question taken up by Stark, one of fundamental importance, is the cause of those vibrations of the electrons which give rise to light-

[1] *Physikalische Zeitschrift*, **6**, 892, 1905; **7**, 249, 251, 353, 355, 564, 567, 1906.

waves. The most natural assumption to make is that the collision or its equivalent which expels an electron from the neutral atom, thus forming the positive ion, sets up violent oscillations of the remaining electrons, and that these gradually lose this energy by radiation until another collision gives them a fresh supply. He points out that if this be the only cause of radiation immediately behind the cathode the slower canal particles ought to radiate more energetically than the faster ones; for the latter are evidently formed farther in front of the cathode than the former, and hence just behind the cathode the fast moving ones have been radiating for a longer time, and the amplitude of the vibration of their electrons would accordingly have decreased more than in the case of the slower ones. Besides, positive ions are evidently also formed in the negative glow, and hence pass through the Crookes-dark space; this dark space ought then to show the line-spectra, which it does not at all in case of hydrogen. Stark's photograph also shows that between the normal line and the displaced line, there is a decided minimum of intensity, indicating that the slow particles are very feeble radiators.

To explain these facts, Stark suggests that the cause of the radiation is to be sought in the velocity of the ion with reference to the ether. Some idea of the mechanism of this may be formed by supposing that the "elastic forces" acting on the electron inside the ion depend upon the relative motion of the ion and the ether. His observations indicate that this force is diminished with increasing relative velocity; and, furthermore, that the force in the direction of motion is diminished more than at right angles to the motion. If this is so, then it is quite conceivable that when an ion is in rapid motion relative to the ether, its electrons may be caused to oscillate in such a manner as to send out light-waves. The pressure of the light emitted by such an ion will decrease its velocity, and by falling on other atoms of the gas will increase their velocity if this be less than that of the radiating ion; here is, then, a cause which tends to produce an equalization of the internal energy of the ions and their energy of translation.

Stark's spectrograms show that the minimum of intensity between the normal line and the displaced line is wider the shorter the wave-length, which indicates that the velocity necessary for the radiation of the shorter wave-lengths is greater than for longer wave-lengths, other things being equal. In case of mercury, the line λ 2536.72 (one of his series of doublets) shows a very narrow minimum, the triplets show a wider minimum, and the line λ 4078.1 a still wider one. The line λ 2536.72 should accordingly appear with relatively low velocity of the ions (low mean tempera-

ture), the triplets should require a somewhat greater velocity (higher temperature), and the line λ 4078.1 a still greater velocity. This has actually been verified, since the line λ 2536.72 may be seen in the Bunsen flame, while a considerable pressure in the mercury arc is necessary to give the line λ 4078.1 with any intensity.

That emission of light as a result of collisions is possible is evident from the fact that all the spectrograms show the lines in their normal positions as well as the displaced lines. Stark seems to regard this as "irregular radiation" or "luminescence," while the radiation due to translation is regarded as "regular" or "pure temperature radiation."

J. A. ANDERSON.

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Resolution of Spectral Lines by Means of Interference Points Produced by Plane-parallel Plates.[1] By E. GEHRCKE and O. VON BAEYER. (Communication from the *Physikalisch-Technische Reichsanstalt.*)

Since the advent of spectroscopic apparatus of high resolving power, the structure of spectral lines has been made the subject of numerous investigations. A comparison of the results obtained with different types of apparatus showed such poor agreement among themselves that it was quite impossible to decide upon the number of components accompanying well-known spectral lines. The discrepancies and contradictions were especially marked when the results obtained with the Lummer and Gehrcke[2] interference plates were compared with those obtained by means of other forms of interference apparatus. As, for example, such lines as the cadmium red (λ 643.9 $\mu\mu$) which the echelon[3] and the Fabry and Pérot[4] interferometers gave as single, appeared to be accompanied by a large number of components when analyzed by means of the Lummer and Gehrcke plate. It was suggested by Fabry and Pérot[5] that many of these supposed components might, in reality, be nothing but ghosts occasioned by imperfections in the interference plates. From all this it is obvious that some criterion by means of which it would be possible to decide upon the position and number of components was highly desirable. In their efforts

[1] *Annalen der Physik*, (4) **20**, 269–292, 1906.

[2] *Ibid.*, (4) **10**, 457–477, 1903.

[3] L. Janicki, *ibid.*, (4) **19**, 36–79, 1906.

[4] *Annales de Chim. et de Phys.*, (7) **22**, 564, 1901.

[5] *Journal de Physique*, (4) **3**, 28–32, 1904.

to find such a criterion the authors were led to the following considerations:

Let it be supposed that a parallel beam of monochromatic light of wave-length λ be first reflected from a Lummer and Gehrcke plate lying in a horizontal position and then from a similar plate standing vertically. The resulting phenomenon as viewed in a telescope would be seen to consist of a number of "interference points" arranged in horizontal and vertical rows. Let it first be assumed that the horizontal plate (I) be perfect, and that the other plate (II) be defective in such a manner as to produce a ghost. The resulting interference pattern would take the form

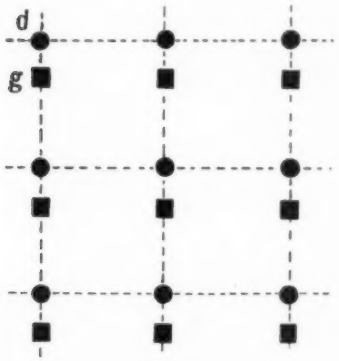

FIG. 1

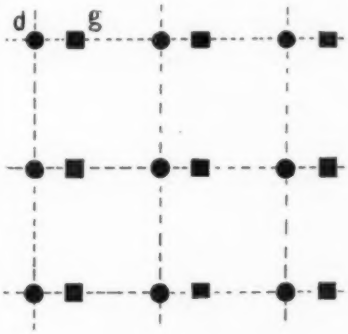

FIG. 2

shown in Fig. 1, where the circular disks *d* represent true interference maxima, while the squares *g* represent ghosts. If on the other hand Plate II be perfect and Plate I defective, it is obvious that the condition of affairs shown in Fig. 2 would exist. This means, then, that ghosts will appear only in the horizontal and vertical rows and not along diagonals. The only condition under which a ghost could appear on a diagonal would be in case the imperfections in both plates were absolutely identical. This state of affairs could, however, be detected at once by the concomitant existence of points in the vertical and horizontal rows completing the rectangle.

If, now, the source of light be changed to one giving rise to the wave-lengths λ and $\lambda+d\lambda$ (both plates being considered perfect), the resulting arrangement of interference points would be that shown in Fig. 3. Here the shaded disks *c* represent the interference maxima of the components $\lambda+d\lambda$. Thus it is evident that true components are not accompanied by corresponding points in the vertical and horizontal rows. To show how

this arrangement would work under the conditions actually met with in practice, let it be supposed that, as before, the two wave-lengths λ and $\lambda+d\lambda$ are present in the incident light and that both plates be defective—each giving rise to one ghost. In such a case the interference points would be arranged as in Fig. 4. Here d represents an interference point due to λ; g and g_2 are the ghosts of this point; c is the interference point of the component $\lambda+d\lambda$, and g'_1 and g'_2 are its ghosts. From the fact that there are no points on AB and FG completing the rectangle of which d and c are diagonally opposite corners, it is clear that c can be put down as a *true* component to the exclusion of g_1, g_2, g'_1, and g'_2.

In order to test these inferences the authors set up an interference

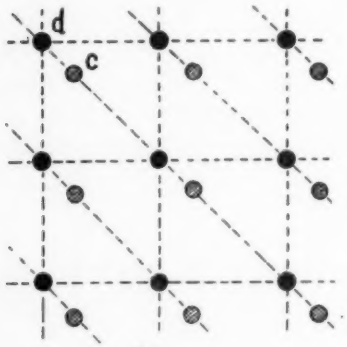

FIG. 3

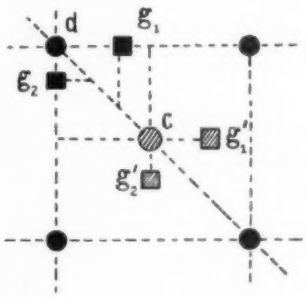

FIG. 4

apparatus of the kind described, using plates which were known to be defective. The magnitude of these defects is shown in the following table;

Plate	μ	Length in cm	Thickness in cm	Variations in Thickness ($\lambda=436\ \mu\mu$)
A.....	1.53	20.0	0.998	$1\frac{1}{2}\lambda$
B.....	1.53	12.5	0.295	$\frac{1}{2}\lambda$
C.....	1.51	20.0	0.503	$\frac{1}{2}\lambda$
D.....	1.53	15.0	0.317	$<\frac{1}{8}\lambda$

In order to obtain photographic records in a reasonable length of time, the authors were forced to use Heraeus quartz lamps containing various metals. The remarkable consistency of the results obtained with different plate-combinations is shown in the following tables, chosen at random from a long list of results presented by the authors. In addition, the best results obtained with the echelon by Janicki and those obtained by Fabry and Pérot are given for the sake of comparison.

GREEN MERCURY LINE
(λ 5461)

GEHRCKE AND BAEYER			JANICKI	PÉROT AND FABRY
Plate A and B	Plate B & C	Plate C & D	Echelon	Silvered Plates
−2.40*	−2.42	−2.41	−2.32	−2.24
−1.20	−1.11	−1.03	−0.99	−0.76
−0.72	−0.71	−0.55	−0.66	−0.52
				+0.08
+0.81	+0.88	+0.93	+0.88	+0.82
+1.25	+1.37	+1.40	+1.33	+1.36

* The results are expressed in terms of 10^{-3} μμ.

In accord with all previous observations, the authors found no components accompanying the red cadmium line (λ 6439).

To show the effectiveness of this new method of telling true components from ghosts, the authors state that in their examination of the green mercury line (λ 5461) by means of plates B and C they were able to count at least nine ghosts—and still the position and number of true components as obtained with these plates is almost identical with that obtained by means of entirely different forms of interferometers. As the object of this review is merely to present the principles involved, it will be necessary to refer to the original article for a detailed account of the results obtained.

The authors further point out that their method which is simply a modification of the well-known "crossed prism method," might equally well be applied to the grating and echelon. By their very ingenious application of this method the authors have most assuredly proved their point; and it must be highly gratifying to all spectroscopists to feel that it is at last possible to determine with definiteness the structure of spectral lines.

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A Popular Guide to the Heavens: A Series of Eighty-three Plates with Explanatory Text and Index. By SIR ROBERT S. BALL. 8vo, pp. 95, with 83 plates and 12 key-maps. London: George Philip & Son, 1905. 15s.

This volume is the result of a revision of the author's *Atlas of Astronomy*, published in 1892. Besides replacing many of the old illustrations with examples of more recent work, many new plates have been added. The new subjects are well chosen and are excellently reproduced. It is to be regretted that all of the drawings of the Moon have been retained.

The exaggerated contrast and unlikeness to what is actually seen in a telescope makes them appear grotesque, and it is doubtful if they have any advantage for purposes of identification over the three photographic reproductions added to the new edition. There are nineteen lunar plates altogether, accompanied by fifteen full-page key-maps. Half this number would have been ample.

Among many features valuable to the amateur and the general reader are to be especially noted the index to planetary phenomena for the next fifty years (fifteen years would have been sufficient), and the star maps. The latter are admirably adapted for ease in identification of the constellations and the brighter stars. While the book is of exceptional value to the amateur and the general public, it will also be found a useful addition to the professional library. S. B. B.

Fünfstellige mathematische und astronomische Tafeln. Von F. BIDSCHOF und A. VITAL. Wien und Leipzig: Franz Deuticke, 1905. Pp. 219. M. 7.50.

These tables are particularly intended for the use of astronomers, geographers, and mariners. The logarithms of the numbers from 1 to 10,000 are so arranged that the arguments are also expressed in arc or time, as in many of the older tables. Addition and subtraction logarithms follow. The trigonometric tables depart from the usual arrangement in adding the values for the cosecant and secant. A total of fifty-eight tables is given, of which about fifty would be of frequent service in astronomical work. Among these may be named Bessel's refractions, table for reducing circum-meridian altitudes, and for latitude from *Polaris;* a compressed table for computing precession, with values for 1900; tables for approximate solution of Kepler's equation, for computing the true anomaly in the parabola. The last fourteen pages of this convenient work contain a summary of the principal formulae of spherical, practical, and theoretical astronomy.

The Royal Society, or Science in the State and in the Schools. By SIR WILLIAM HUGGINS. London: Methuen & Co., 1906. Pp. 131, with 25 illustrations. 4*s.* 6*d.*

This handsome volume appropriately records in a form adapted to a general circulation, four of the official addresses of Sir William Huggins during his five years of service as president of the Royal Society. A preliminary chapter gives an interesting account of the early history of the

society. The topics of the four addresses are: (1902) Supreme Importance of Science to the Industries of the Country, which Can Be Secured only Through making Science an Essential Part of All Education; (1903) The Relation of the Royal Society to the Specialized Scientific Societies; (1904) The Advisory Relation of the Royal Society to the State, and the Responsible Public Duties which Rest Permanently upon the Society; (1905) The Profound Influence which Science, Represented by the Royal Society, Has Had upon the Life and Thought of the World; and the Place of Science in General Education; Science in Education.

The book is embellished with several illustrations due to the accomplished hand of Lady Huggins, with halftone reproductions which include the death mask-of Sir Isaac Newton, and his original reflecting telescope, and with excellent portraits "of ten Fellows of immortal fame in science."

ERRATA

Astrophysical Journal, Vol. **23**, June 1906, in Professor Vogel's article on "Reflecting Telescopes of Relatively Short Focus":

Page 372, tenth line from top, *for* where these wave-lengths unite, *read* where the rays of these wave-lengths unite.

Page 373, ninth line from foot, *add* **19**, 21, 1898: H. C. Plummer, "On the Star-Image Formed by a Parabolic Mirror?"

Page 379, ninth line from foot, *for* center, *read* diameter.

Page 382, fifteenth and sixteenth lines from top, *transpose* from the vertex, *so that it shall follow the word* figure.

Page 388, eighteenth line from top, *for* a, *read* the.

Page 388, seventh line from foot, *for* should, *read* could.

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HERMANN KOBOLD: *Der Bau des Fixsternsystems.* Pp. 256, Figs. 19 and 3 charts. Braunschweig: F. Vieweg & Sohn, 1906. M. 6.60.

L. BOLTZMANN: *Leçons sur la théorie des gaz,* traduites par A. GALLOTTI et H. BENARD, avec une introduction et des notes de M. BRILLOUIN. Seconde Partie. Pp. 280. Paris: Gauthier-Villars, 1905.

L. PFAUNDLER: *Müller-Pouillets Lehrbuch der Physik und Meteorologie.* Zehnte umgearbeitete und vermehrte Auflage. Band I. Pp. 801, Figs. 838. Braunschweig: F. Vieweg & Sohn, 1906. M. 10.50.

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O. D. CHWOLSON: *Traité de physique,* ouvrage traduit sur les éditions russe et allemande par E. DAVAUX. Édition revue et considérablement augmentée par l'auteur, suivie de notes sur la physique théorique par E. COSSERAT et F. COSSERAT. Paris: A. Hermann, 1906.

Tome premier: Introduction, Mécanique, Méthodes et Instruments de mesure; L'état gazeux des corps. Pp. 559, Figs. 279. Fr. 22.

Tome deuxiéme: Émission et absorption de l'énergie rayonnante, Vitesse de propagation, Réflexion et Réfraction. L'indice de réfraction, Dispersion et transformation de l'énergie rayonnante. Avec une note de M. de GRAMONT sur lés methodes modernes en analyse spectrale. Pp. 431, Figs. 262. Fr. 16.

R. A. MILLIKAN and H. G. GALE: *A First Course in Physics.* Pp. 493, and portraits of scientists. Boston: Ginn & Co., 1906. $1.40.

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W. H. WHEELER: *A Practical Manual of Tides and Waves.* Pp. 201, Figs. 19. London: Longmans, Green & Co., 1906.

T. E. HEATH: *Our Stellar Universe, A Road Book to the Stars.* Pp. 74, Figs. 8. London: King, Sell & Olding, 1905. 5 *s.* net.

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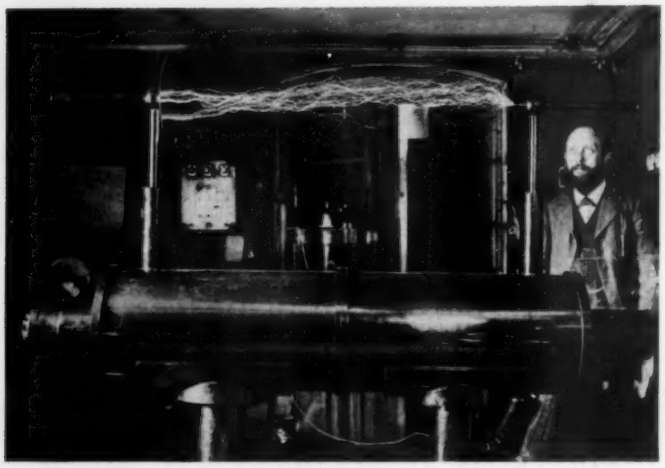

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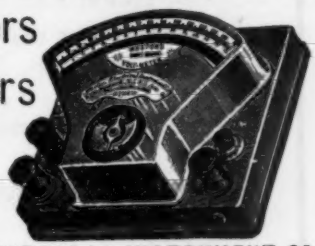

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The inscriptions are arranged chronologically, and span the period from 4241 to 525 B. C. Besides the English translations, introductory notes are given furnishing all the data necessary for the intelligent study of the texts. For ease of reference each document is divided into brief paragraphs numbered consecutively, and is accompanied by a series of running footnotes explaining obscure passages.

A separate index volume was announced provisionally in the first prospectus. This is now in an advanced stage of preparation and will be issued about January 1. It will contain the following separate indices: I, Divine Names; II, Temples; III, Kings; IV, Persons; V, Titles, Offices, and Ranks; VI, Geographical; VII, Miscellaneous; VIII, Egyptian; IX, Hebrew; X, Arabic; XI, Lepsius' *Denkmäler* and Text.

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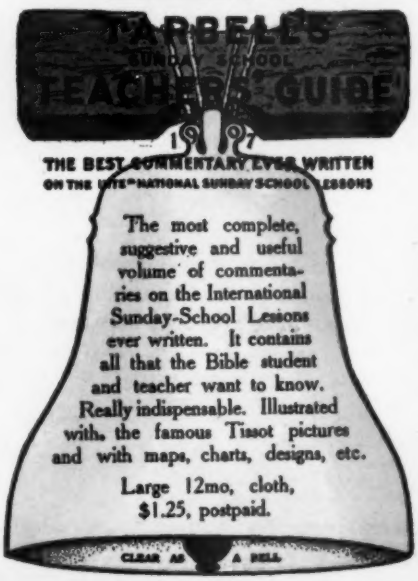
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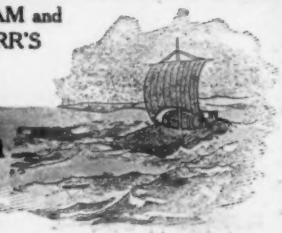

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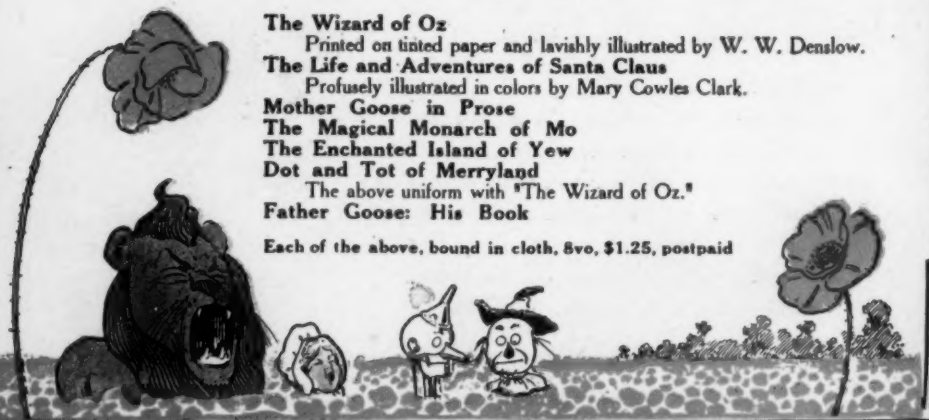

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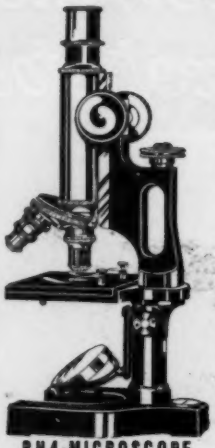

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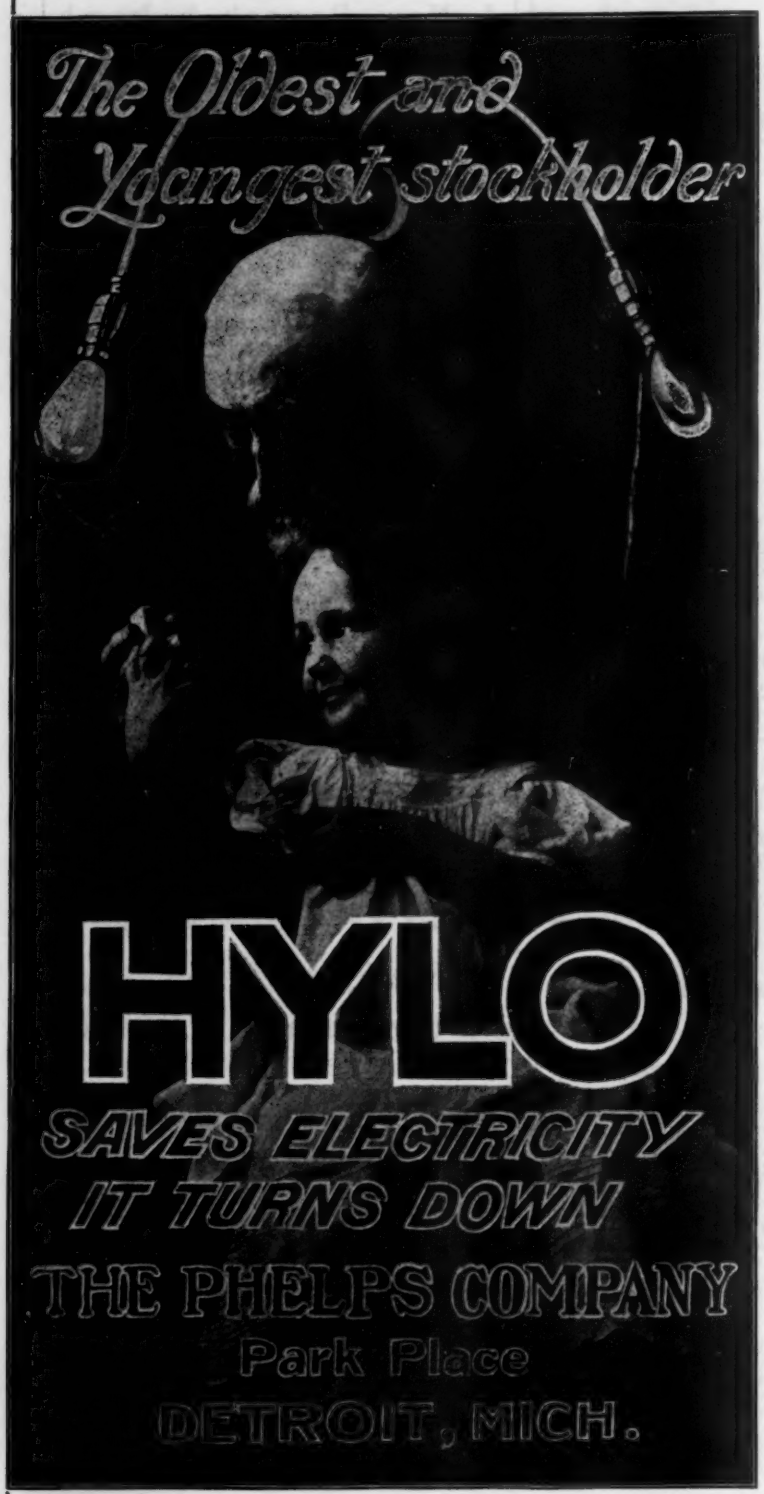

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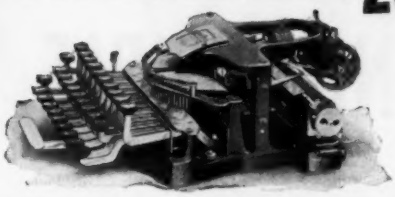

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